PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : C12N 15/29, 5/04, 15/82, A01H 4/00, 5/00

A1

(11) International Publication Number: WO 99/31243

(43) International Publication Date: 24 June 1999 (24.06.99)

(21) International Application Number: PCT/US98/26784

(22) International Filing Date: 16 December 1998 (16.12.98)

(30) Priority Data:
08/991,677 16 December 1997 (16.12.97) US

(71) Applicant *(for all designated States except US)*: INTERNATIONAL PAPER COMPANY [US/US]; 2 Manhattanville Road, Purchase, NY 10577-2196 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: CHIANG, Vincent, L. [US/US]; 1104 Birch Street, Hancock, MI 49930 (US). CARRAWAY, Daniel, T. [US/US]; 1910 Rich Street, Bainbridge, GE 31717 (US). SMELTZER, Richard, H. [US/US]; 5036 Valley Farm Road, Tallahassee, FL 32303 (US).

(74) Agents: GRAHAM, Mark, S.; Luedeka, Neely & Graham, P.C., P.O. Box 1871, Knoxville, TN 37901 (US) et al.

(81) Designated States: BR, CA, CN, FI, ID, MX, NO, NZ, PL, RU, SE, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: PRODUCTION OF SYRINGYL LIGNIN IN GYMNOSPERMS

(57) Abstract

The present invention relates to a method for producing syringyl lignin in gymnosperms. The production of syringyl lignin in gymnosperms is accomplished by genetically transforming a gymnosperm genome, which does not normally contain genes which code for enzymes necessary for production of syringyl lignin, with DNA which codes for enzymes found in angiosperms associated with production of syringyl lignin. The expression of the inserted DNA is mediated using host promoter regions in the gymnosperm. In addition, genetic sequences which code for gymnosperm lignin anti-sense mRNA may be incorporated into the gymnosperm genome in order to suppress the formation of the less preferred forms of lignin in the gymnosperm such as guaiacyl lignin.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania
AM	Armenia
AT	Austria
AU	Australia
AZ	Azerbaijan
BA	Bosnia and Herzegovina
BB	Barbados
BE	Belgium
BF	Burkina Faso
BG	Bulgaria
BJ	Benin
BR	Brazil
BY	Belarus
CA	Canada
CF	Central African Republic
CG	Congo
CH	Switzerland
CI	Côte d'Ivoire
CM	Cameroon
CN	China
CU	Cuba
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
ES	Spain
FI	Finland
FR	France
GA	Gabon
GB	United Kingdom
GE	Georgia
GH	Ghana
GN	Guinea
GR	Greece
HU	Hungary
IE	Ireland
IL	Israel
IS	Iceland
IT	Italy
JP	Japan
KE	Kenya
KG	Kyrgyzstan
KP	Democratic People's Republic of Korea
KR	Republic of Korea
KZ	Kazakstan
LC	Saint Lucia
LI	Liechtenstein
LK	Sri Lanka
LR	Liberia
LS	Lesotho
LT	Lithuania
LU	Luxembourg
LV	Latvia
MC	Monaco
MD	Republic of Moldova
MG	Madagascar
MK	The former Yugoslav Republic of Macedonia
ML	Mali
MN	Mongolia
MR	Mauritania
MW	Malawi
MX	Mexico
NE	Niger
NL	Netherlands
NO	Norway
NZ	New Zealand
PL	Poland
PT	Portugal
RO	Romania
RU	Russian Federation
SD	Sudan
SE	Sweden
SG	Singapore
SI	Slovenia
SK	Slovakia
SN	Senegal
SZ	Swaziland
TD	Chad
TG	Togo
TJ	Tajikistan
TM	Turkmenistan
TR	Turkey
TT	Trinidad and Tobago
UA	Ukraine
UG	Uganda
US	United States of America
UZ	Uzbekistan
VN	Viet Nam
YU	Yugoslavia
ZW	Zimbabwe

PRODUCTION OF SYRINGYL LIGNIN IN GYMNOSPERMS

Field of the Invention

This application claims the benefit of U.S. Provisional Application number 60/033,381, filed December 16, 1996. The invention relates to the molecular modification of gymnosperms in order to cause the production of syringyl units during lignin biosynthesis and to production and propagation of gymnosperms containing syringyl lignin.

Background of the Invention

Lignin is a major part of the supportive structure of most woody plants including angiosperm and gymnosperm trees which in turn are the principal sources of fiber for making paper and cellulosic products. In order to liberate fibers from wood structure in a manner suitable for making many grades of paper, it is necessary to remove much of the lignin from the fiber/lignin network. Lignin is removed from wood chips by treatment of the chips in an alkaline solution at elevated temperatures and pressure in an initial step of papermaking processes. The rate of removal of lignin from wood of different tree species varies depending upon lignin structure. Three different lignin structures have been identified in trees: p-hydroxyphenyl, guaiacyl and syringyl, which are illustrated in Fig. 1.

Angiosperm species, such as *Liquidambar styraciflua* L. [sweetgum], have lignin composed of a mixture of guaiacyl and syringyl monomer units. In contrast, gymnosperm species such as *Pinus taeda* L. [loblolly pine] have lignin which is devoid of syringyl monomer units. Generally speaking, the rate of delignification in a pulping process is directly proportional to the amount of syringyl lignin present in the wood. The higher delignification rates associated with species having a greater proportion of syringyl lignin result in more efficient pulp mill operations since the mills make better use of energy and capital investment and the environmental impact is lessened due to a decrease in chemicals used for delignification.

It is therefore an object of the invention to provide gymnosperm species which are easier to delignify in pulping processes.

Another object of the invention is to provide gymnosperm species such as loblolly pine which contain syringyl lignin.

An additional object of the invention is to provide a method for modifying genes involved in lignin biosynthesis in gymnosperm species so that production of syringyl lignin is increased while production of guaiacyl lignin is suppressed.

Still another object of the invention is to produce whole gymnosperm plants containing genes which increase production of syringyl lignin and repress production of guaiacyl lignin.

Yet another object of the invention is to identify, isolate and/or clone those genes in angiosperms responsible for production of syringyl lignin.

A further object of the invention is to provide, in gymnosperms, genes which produce syringyl

lignin.

Another object of the invention is to provide a method for making an expression cassette insertable into a gymnosperm cell for the purpose of inducing formation of syringyl lignin in a gymnosperm plant derived from the cell.

Definitions

The term "promoter" refers to a DNA sequence in the 5' flanking region of a given gene which is involved in recognition and binding of RNA polymerase and other transcriptional proteins and is required to initiate DNA transcription in cells.

The term "constitutive promoter" refers to a promoter which activates transcription of a desired gene, and is commonly used in creation of an expression cassette designed for preliminary experiments relative to testing of gene function. An example of a constitutive promoter is 35S CaMV, available from Clonetech.

The term "expression cassette" refers to a double stranded DNA sequence which contains both promoters and genes such that expression of a given gene is acheived upon insertion of the expression cassette into a plant cell.

The term "plant" includes whole plants and portions of plants, including plant organs (e.g. roots, stems, leaves, etc.)

The term "angiosperm" refers to plants which produce seeds encased in an ovary. A specific example of an angiosperm is *Liquidambar styraciflua* (L.)[sweetgum]. The angiosperm sweetgum produces syringyl lignin.

The term "gymnosperm" refers to plants which produce naked seeds, that is, seeds which are not encased in an ovary. A specific example of a gymnosperm is *Pinus taeda* (L.)[loblolly pine]. The gymnosperm loblolly pine does not produce syringyl lignin.

Summary of the Invention

With regard to the above and other objects, the invention provides a method for inducing production of syringyl lignin in gymnosperms and to gymnosperms which contain syringyl lignin for improved delignification in the production of pulp for papermaking and other applications. In accordance with one of its aspects, the invention involves cloning an angiosperm DNA sequence which codes for enzymes involved in production of syringyl lignin monomer units, fusing the angiosperm DNA sequence to a lignin promoter region to form an expression cassette, and inserting the expression cassette into a gymnosperm genome.

Enzymes required for production of syringyl lignin in an angiosperm are obtained by deducing an amino acid sequence of the enzyme, extrapolating an mRNA sequence from the amino acid sequence, constructing a probe for the corresponding DNA sequence and cloning the DNA sequence which codes for the desired enzyme. A promoter region specific to a gymnosperm lignin biosynthesis

gene is identified by constructing a probe for a gymnosperm lignin biosynthesis gene, sequencing the 5' flanking region of the DNA which encodes the gymnosperm lignin biosynthesis gene to locate a promoter sequence, and then cloning that sequence.

An expression cassette is constructed by fusing the angiosperm syringyl lignin DNA sequence to the gymnosperm promoter DNA sequence. Alternatively, the angiosperm syringyl lignin DNA is fused to a constitutive promoter to form an expression cassette. The expression cassette is inserted into the gymnosperm genome to transform the gymnosperm genome. Cells containing the transformed genome are selected and used to produce a transformed gymnosperm plant containing syringyl lignin.

In accordance with the invention, the angiosperm gene sequences bi-OMT, 4CL, P450-1 and P450-2 have been determined and isolated as associated with production of syringyl lignin in sweetgum and lignin promoter regions for the gymnosperm loblolly pine have been determined to be the 5' flanking regions for the 4CL1B, 4CL3B and PAL gymnosperm lignin genes. Expression cassettes containing sequences of selected genes from sweetgum have been inserted into loblolly pine embryogenic cells and presence of sweetgum genes associated with production of syringyl lignin has been confirmed in daughter cells of the resulting loblolly pine embryogenic cells.

The invention therefore enables production of gymnosperms such as loblolly pine containing genes which code for production of syringyl lignin, to thereby produce in such species syringyl lignin in the wood structure for enhanced pulpability.

<u>Brief Description of the Drawings</u>

The above and other aspects of the invention will now be further described in the following detailed specification considered in conjunction with the following drawings in which:

Fig. 1 illustrates a generalized pathway for lignin synthesis; and

Fig. 2 illustrates a bifunctional-O-methyl transferase (bi-OMT) gene sequence involved in the production of syringyl lignin in an angiosperm (SEQ ID 5 and 6);

Fig. 3 illustrates a 4-coumarate CoA ligase (4CL) gene sequence involved in the production of syringyl lignin in an angiosperm (SEQ ID 7 and 8);

Fig. 4 illustrates a P450-1 gene sequence involved in the production of syringyl lignin in an angiosperm (SEQ ID 1 and 2);

Fig. 5 illustrates a P450-2 gene sequence involved in the production of syringyl lignin in an angiosperm (SEQ ID 3 and 4);

Fig. 6 illustrates nucleotide sequences of the 5' flanking region of the loblolly pine 4CL1B gene showing the location of regulatory elements for lignin biosynthesis (SEQ ID 10);

Fig. 7 illustrates nucleotide sequences of the 5' flanking region of the loblolly pine 4CL3B gene showing the location of regulatory elements for lignin biosynthesis (SEQ ID 11);

Fig. 8 illustrates nucleotide sequences of the 5' flanking region of loblolly pine PAL gene

showing the location of regulatory elements for lignin biosynthesis (SEQ ID 9);

Fig. 9 illustrates a PCR confirmation of the sweetgum P450-1 gene sequence in transgenic loblolly pine cells.

Detailed Description of the Invention

In accordance with the invention, a method is provided for modifying a gymnosperm genome, such as the genome of a loblolly pine, so that syringyl lignin will be produced in the resulting plant, thereby enabling cellulosic fibers of the same to be more easily separated from lignin in a pulping process. In general, this is accomplished by fusing one or more angiosperm DNA sequences (referred to at times herein as the "ASL DNA sequences") which are involved in production of syringyl lignin to a gymnosperm lignin promoter region (referred to at times herein as the "GL promoter region") specific to genes involved in gymnosperm lignin biosynthesis to form a gymnosperm syringyl lignin expression cassette (referred to at times herein as the "GSL expression cassette"). Alternatively, the one or more ASL DNA sequences are fused to one or more constitutive promoters to form a GSL expression cassette.

The GSL expression cassette preferably also includes selectable marker genes which enable transformed cells to be differentiated from untransformed cells. The GSL expression cassette containing selectable marker genes is inserted into the gymnosperm genome and transformed cells are identified and selected, from which whole gymnosperm plants may be produced which exhibit production of syringyl lignin.

To suppress production of less preferred forms of lignin in gymnosperms, such as guaiacyl lignin, genes from the gymnosperm associated with production of these less preferred forms of lignin are identified, isolated and the DNA sequence coding for anti-sense mRNA (referred to at times herein as the "GL anti-sense sequence") for these genes is produced. The DNA sequence coding for anti-sense mRNA is then incorporated into the gymnosperm genome, which when expressed bind to the less preferred guaiacyl gymnosperm lignin mRNA, inactivating it.

Further features of these and various other steps and procedures associated with practice of the invention will now be described in more detail beginning with identification and isolation of ASL DNA sequences of interest for use in inducing production of syringyl lignin in a gymnosperm.

I. Determination of DNA Sequence For Genes Associated with Production of Syringyl Lignin

The general biosynthetic pathway for production of lignin has been postulated as shown in Fig. 1. From Fig. 1, it can be seen that the genes CCL, OMT and F5H (which is from the class of P450 genes) may play key roles in production of syringyl lignin in some plant species, but their specific contributions and mechanisms remain to be positively established. It is suspected that the CCL, OMT and F5H genes may have specific equivalents in a specific angiosperm, such as sweetgum. Accordingly, one aim of the present invention is to identify, sequence and clone specific genes of

interest from an angiosperm such as sweetgum which are involved in production of syringyl lignin and to then introduce those genes into the genome of a gymnosperm, such as loblolly pine, to induce production of syringyl lignin.

Genes of interest may be identified in various ways, depending on how much information about the gene is already known. Genes believed to be associated with production of syringyl lignin have already been sequenced from a few angiosperm species, viz, CCL and OMT.

DNA sequences of the various CCL and OMT genes are compared to each other to determine if there are conserved regions. Once the conserved regions of the DNA sequences are identified, primers homologous to the conserved sequences are synthesized. Reverse transcription of the DNA-free total RNA which was purified from sweetgum xylem tissue, followed by double PCR using gene-specific primers, enables production of probes for the CCL and OMT genes.

A sweetgum cDNA library is constructed in a host, such as lambda ZAPII, available from Stratagene, of LaJolla, CA, using poly(A) +RNA isolated from sweetgum xylem, according to the methods described by Bugos et al. (1995 Biotechniques 19:734-737). The above mentioned probes are used to assay the sweetgum cDNA library to locate cDNA which codes for enzymes involved in production of syringyl lignin. Once a syringyl lignin sequence is located, it is then cloned and sequenced according to known methods which are familiar to those of ordinary skill.

In accordance with the invention, two sweetgum syringyl lignin genes have been determined using the above-described technique. These genes have been designated 4CL and bi-OMT. The sequence obtained for the sweetgum syringyl lignin gene, designated bi-OMT, is illustrated in Fig. 2 (SEQ ID 5 and 6). The sequence obtained for the sweetgum syringyl lignin gene, designated 4CL, is illustrated in Fig. 3 (SEQ ID 7 and 8).

An alternative procedure was employed to identify the F5H equivalent genes in sweetgum. Because the DNA sequences for similar P450 genes from other plant species were known, probes for the P450 genes were designed based on the conserved regions found by comparing the known sequences for similar P450 genes. The known P450 sequences used for comparison include all plant P450 genes in the GenBank database. Primers were designed based on two highly conserved regions which are common to all known plant P450 genes. The primers were then used in a PCR reaction with the sweetgum cDNA library as a template. Once P450-like fragments were located, they were amplified using standard PCR techniques, cloned into a pBluescript vector available from Stratagene of LaJolla, CA and transformed into a DH5α *E. coli* strain available from Gibco BRL of Gaithersburg, MD.

After *E. coli* colonies were tested in order to determine that they contained the P450-like DNA fragments, the fragments were sequenced. Several P450-like sequences were located in sweetgum using the above described technique. One P450-like sequence was sufficiently different from other

known P450 sequences to indicate that it represented a new P450 gene family. This potentially new P450 cDNA fragment was used as a probe to screen two full length clones from the sweetgum xylem cDNA library. These putative hydroxylase clones were designated P450-1 and P450-2. The sequences obtained for P450-1 and P450-2 are illustrated in Fig. 4 (SEQ ID 1 and 2) and Fig. 5 (SEQ ID 3 and 4).

II. Identification of GL Gene Promoter Regions

In order to locate gymnosperm lignin promoter regions, probes are developed to locate lignin genes. After the gymnosperm lignin gene is located, the portion of DNA upstream from the gene is sequenced, preferably using the GenomeWalker Kit, available from Clontech. The portion of DNA upstream from the lignin gene will generally contain the gymnosperm lignin promoter region.

Gymnosperm genes of interest include CCL-like genes and PAL-like genes, which are beleived to be involved in the production of lignin in gymnosperms. Preferred probe sequences are developed based on previously sequenced genes, which are available from the gene bank. The preferred gene bank accession numbers for the CCL-like genes include U39404 and U39405. A preferred gene bank accession number for a PAL-like gene is U39792. Probes for such genes are constructed according to methods familiar to those of ordinary skill in the art. A genomic DNA library is constructed and DNA fragments which code for gymnosperm lignin genes are then identified using the above mentioned probes. A preferred DNA library is obtained from the gymnosperm, *Pinus taeda* (L.)[Loblolly Pine], and a preferred host of the genomic library is Lambda DashII, available from Stratagene of LaJolla, CA.

Once the DNA fragments which code for the gymnosperm lignin genes are located, the genomic region upstream from the gymnosperm lignin gene (the 5'flanking region) was identified. This region contains the GL promoter. Three promoter regions were located from gymnosperm lignin biosynthesis genes. The first is the 5'flanking region of the loblolly pine 4CL1B gene, shown in Fig. 6 (SEQ ID 10). The second is the 5' flanking region of the loblolly pine gene 4CL3B, shown in Fig. 7 (SEQ ID 11). The third is the 5' flanking region of the loblolly pine gene PAL, shown in Fig. 8 (SEQ ID 9).

III. Fusing the GL Promoter Region to the ASL DNA Sequence

The next step of the process is to fuse the GL promoter region to the ASL DNA sequence to make a GSL expression cassette for insertion into the genome of a gymnosperm. This may be accomplished by standard techniques. In a preferred method, the GL promoter region is first cloned into a suitable vector. Preferred vectors are pGEM7Z, available from Promega, Madison, WI and SK available from Stratagene, of LaJolla, CA. After the promoter sequence is cloned into the vector, it is then released with suitable restriction enzymes. The ASL DNA sequence is released with the same restriction enzyme(s) and purified.

The GL promoter region sequence and the ASL DNA sequence are then ligated such as with T4 DNA ligase, available from Promega, to form the GSL expression cassette. Fusion of the GL and ASL DNA sequence is confirmed by restriction enzyme digestion and DNA sequencing. After confirmation of GL promoter-ASL DNA fusion, the GSL expression cassette is released from the original vector with suitable restriction enzymes and used in construction of vectors for plant transformation.

IV. Fusing the ASL DNA Sequence to a Constitutive Promoter Region

In an alternative embodiment, a standard constitutive promoter may be fused with the ASL DNA sequence to make a GSL expression cassette. For example, a standard constitutive promoter may be fused with P450-1 to form an expression cassette for insertion of P450-1 sequences into a gymnosperm genome. In addition, a standard constitutive promoter may be fused with P450-2 to form an expression cassette for insertion of P450-2 into a gymnosperm genome. A constitutive promoter for use in the invention is the double 35S promoter.

In the preferred practice of the invention using constitutive promoters, a suitable vector such as pBI221, is digested by XbaI and HindIII to release the 35S promoter. At the same time the vector pHygro, available from International Paper, was digested by XbaI and HindIII to release the double 35S promoter. The double 35S promoter was ligated to the previously digested pBI221 vector to produce a new pBI221 with the double 35S promoter. This new pBI221 was digested with SacI and SmaI, to release the GUS fragment. The vector is next treated with T4 DNA polymerase to produce blunt ends and the vector is self-ligated. This vector is then further digested with BamHI and XbaI, available from Promega. After the pBI221 vector containing the constitutive promoter region has been prepared, lignin gene sequences are prepared for insertion into the pBI221 vector.

The coding regions of sweetgum P450-1 or P450-2 are amplified by PCR using primer with restriction sites incorporated in the 5' and 3' ends. In one example, an XbaI site was incorporated at the 5' end and a BamHI site was incorporated at the 3' end of the sweetgum P450-1 or P450-2 genes. After PCR, the P450-1 and P450-2 genes were separately cloned into a TA vector available from Invitrogen. The TA vectors containing the P450-1 and P450-2 genes, respectively, were digested by XbaI and BamHI to release the P450-1 or P450-2 sequences.

The p35SS vector, described above, and the isolated sweetgum P450-1 or P450-2 fragments were then ligated to make GLS expression cassettes containing the constitutive promoter.

V. Inserting the Expression Cassette into the Gymnosperm Genome

There are a number of methods by which the GSL expression cassette may be inserted into a target gymnosperm cell. One method of inserting the expression cassette into the gymnosperm is by micro-projectile bombardment of gymnosperm cells. For example, embryogenic tissue cultures of loblolly pine may be initiated from immature zygotic embryos. Tissue is maintained in an undifferentiated state on semi-solid proliferation medium. For transformation, embryogenic tissue is

suspended in liquid proliferation medium. Cells are then sieved through, a preferably 40 mesh screen, to separate small, densely cytoplasmic cells from large vacuolar cells.

After separation, a portion of the liquid cell suspension fraction is vacuum deposited onto filter paper and placed on semi-solid proliferation medium. The prepared gymnosperm target cells are then grown for several days on filter paper discs in a petri dish.

A 1:1 mixture of plasmid DNA containing the selectable marker expression cassette and plasmid DNA containing the P450-1 expression cassette may be precipitated with gold to form microprojectiles. The microprojectiles are rinsed in absolute ethanol and aliqots are dried onto a suitable macrocarrier such as the macrocarrier available from BioRad in Hercules, CA.

Prior to bombardment, embryogenic tissue is preferably desiccated under a sterile laminar-flow hood. The desiccated tissue is transferred to semi-solid proliferation medium. The prepared microprojectiles are accelerated from the macrocarrier into the desiccated target cells using a suitable apparatus such as a BioRad PDS-1000/HE particle gun. In a preferred method, each plate is bombarded once, rotated 180 degrees, and bombarded a second time. Preferred bombardment parameters are 1350 psi rupture disc pressure, 6 mm distance from the rupture disc to macrocarrier (gap distance), 1 cm macrocarrier travel distance, and 10 cm distance from macrocarrier stopping screen to culture plate (microcarrier travel distance). Tissue is then transferred to semi-solid proliferation medium containing a selection agent, such as hygromycin B, for two days after bombardment.

Other methods of inserting the GSL expression cassette include use of silicon carbide whiskers, transformed protoplasts, *Agrobacterium* vectors and electroporation.

VI. Identifying Transformed Cells

In general, insertion of the GSL expression cassette will typically be carried out in a mass of cells and it will be necessary to determine which cells harbor the recombinant DNA molecule containing the GSL expression cassette. Transformed cells are first identified by their ability to grow vigorously on a medium containing an antibiotic which is toxic to non-transformed cells. Preferred antibiotics are kanamycin and hygromycin B. Cells which grow vigorously on antibiotic containing medium are further tested for presence of either portions of the plasmid vector, the syringyl lignin genes in the GSL expression cassette; e.g. the angiosperm bi-OMT, 4CL, P450-1 or P450-2 gene, or by testing for presence of other fragments in the GSL expression cassette. Specific methods which can be used to test for presence of portions of the GSL expression cassette include Southern blotting with a labeled complementary probe or PCR amplification with specific complementary primers. In yet another approach, an expressed syringyl lignin enzyme can be detected by Western blotting with a specific antibody, or by assaying for a functional property such as the appearance of functional enzymatic activity.

VII. Production of a Gymnosperm Plant from the Transformed Gymnosperm Cell

Once transformed embryogenic cells of the gymnosperm have been identified, isolated and multiplied, they may be grown into plants. It is expected that all plants resulting from transformed cells will contain the GSL expression cassette in all their cells, and that wood in the secondary growth stage of the mature plant will be characterized by the presence of syringyl lignin.

Transgenic embryogenic cells are allowed to replicate and develop into a somatic embryo, which are then converted into a somatic seedling.

VIII. Identification, Production and Insertion of a GL mRNA Anti-Sense Sequence

In addition to adding ASL DNA sequences, anti-sense sequences may be incorporated into a gymnosperm genome, via GSL expression cassettes, in order to suppress formation of the less preferred native gymnosperm lignin. To this end, the gymnosperm lignin gene is first located and sequenced in order to determine its nucleotide sequence. Methods for locating and sequencing amino acids which have been previously discussed may be employed. For example, if the gymnosperm lignin gene has already been purified, standard sequencing methods may be employed to determine the DNA nucleic acid sequence.

If the gymnosperm lignin gene has not been purified and functionally similar DNA or mRNA sequences from similar species are known, those sequences may be compared to identify highly conserved regions and this information used as a basis for the construction of a probe. A gymnosperm cDNA or genomic library can be probed with the above mentioned sequences to locate the gymnosperm lignin cDNA or genomic DNA. Once the gymnosperm lignin DNA is located, it may be sequenced using standard sequencing methods.

After the DNA sequence has been obtained for a gymnosperm lignin sequence, the complementary anti-sense strand is constructed and incorporated into an expression cassette. For example, the GL mRNA anti-sense sequence may be fused to a promoter region to form an expression cassette as described above. In a preferred method, the GL mRNA anti-sense sequence is incorporated into the previously discussed GSL expression cassette which is inserted into the gymnosperm genome as described above.

IX. Inclusion of Cytochrome P450 Reductase (CPR) to Enhance Biosynthesis of Syringyl Lignin in Gymnosperms

In the absence of external cofactors such as NADPH (an electron donor in reductive biosyntheses), certain angiosperm lignin genes such as the P450 genes may remain inactive or not acheive full or desired activity after insertion into the genome of a gymnosperm. Inactivity or insufficient activity can be determined by testing the resulting plant which contains the P450 genes for the presence of syringyl lignin in secondary growth. It is known that cytochrome P450 reductase (CPR) may be involved in promoting certain reductive biochemical reactions, and may activate the desired

expression of genes in many plants. Accordingly, if it is desired to enhance the expression of the angiosperm syringyl lignin genes in the gymnosperm, CPR may be inserted in the gymnosperm genome. In order to express CPR, the DNA sequence of the enzyme is ligated to a constitutive promoter or, for a specific species such as loblolly pine, xylem-specific lignin promoters such as PAL, 4CL1B or 4CL3B to form an expression cassette. The expression cassette may then be inserted into the gymnosperm genome by various methods as described above.

X. Examples

The following non-limiting examples illustrate further aspects of the invention. In these examples, the angiosperm is *Liquidambar styraciflua* (L.)[sweetgum] and the gymnosperm is *Pinus taeda* (L.)[loblolly pine]. The nomenclature for the genes referred to in the examples is as follows:

Genes	Biochemical Name
4CL (angiosperm)	4-coumarate CoA ligase
bi-OMT (angiosperm)	bifunctional-O-methyl transferase
P450-1 (angiosperm)	cytochrome P450
P450-2 (angiosperm)	cytochrome P450
PAL (gymnosperm)	phenylalanine ammonia-lyase
4CL1B (gymnosperm)	4-coumarate CoA ligase
4CL3B (gymnosperm)	4-coumarate CoA ligase

Example 1 - Isolating and Sequencing bi-OMT and 4CL Genes from an Angiosperm

A cDNA library for Sweetgum was constructed in Lambda ZAPII, available from Stratagene, of LaJolla, CA, using poly(A) +RNA isolated from Sweetgum xylem tissue. Probes for bi-OMT and 4CL were obtained through reverse transcription of their mRNAs and followed by double PCR using gene-specific primers which were designed based on the OMT and CCL cDNA sequences obtained from similar genes cloned from other species.

Four primers were used for amplifying OMT fragments. One was an oligo-dT primer. One was a bi-OMT primer, (which was used to clone gene fragments through modified differential display technique, as described below in Example 2) and the other two were degenerate primers, which were based on the conserved sequences of all known OMTs. The two degenerate primers were derived based on the following amino acid sequences:

5'- Gly Gly Met Ala Thr Tyr Cys Cys Ala Thr Thr Tyr Ala Ala Cys Ala Ala Gly Gly Cys-3' (primer #22) and

3'-Ala Ala Ala Gly Ala Gly Ala Gly Asn Ala Cys Asn Asn Ala Asn Asn Ala Asn Gly Ala-5'

(primer #23).

A 900 bp PCR product was produced when oligo-dT primer and primer #22 were used, and a 550 bp fragment was produced when primer numbers 22 and 23 were used.

Three primers were used for amplifying CCL fragments. They were derived from the following amino acid sequences:

5'-Thr Thr Gly Gly Ala Thr Cys Cys Gly Gly Ile Ala Cys Ile Ala Cys Ile Gly Gly Ile Tyr Thr Ile Cys Cys Ile Ala Ala Arg Gly Gly-3' (primer R1S)

5'-Thr Thr Gly Gly Ala Thr Cys Cys Gly Thr Ile Gly Thr Ile Gly Cys Ile Cys Ala Arg Cys Ala Arg Gly Thr Ile Gly Ala Tyr Gly Gly-3' (primer H1S) and

3'-Cys Cys Ile Cys Thr Tyr Thr Ala Asp Ala Cys Arg Thr Ala Asp Gly Cys Ile Cys Cys Ala Gly Cys Thr Gly Thr Ala-5' (primer R2A)

R1S and H1S were both sense primers. Primer R2A was an anti-sense primer. A 650 bp fragment was produced if R1S and R2A primers were used and a 550 bp fragment was produced when primers H1S and R2A were used. The sequence of these three primers were derived from conserved sequences for plant CCLs.

The reverse transcription-double PCR cloning technique used for these examples consisted of adding 10 μg of DNA-free total RNA in 25μl DEPC-treated water to a microfuge tube. Next, the following solutions were added:

a. 5x Reverse transcript buffer 8.0μl,
b. 0.1 M DTT 4.0 μl
c. 10 mM dNTP 2.0 μl
d. 100 μM oligo-dT primers 8.0 μl
e. Rnasin 2.0 μl
f. Superscript II 1.0 μl

After mixing, the tube was incubated at a temperature of 42° C for one (1) hour, followed by incubation at 70° C for fifteen (15) minutes. Forty (40) μl of 1N NaOH was added and the tube was further incubated at 68° C for twenty (20) minutes. After the incubation periods, 80 μl of 1N HCl was added to the reaction mixture. At the same time, 17 μl NaOAc, 5 μl glycogen and 768 μl of 100% ethanol were added and the reaction mixture was maintained at -80° C for 15 minutes in order to precipitate the cDNA. The precipitated cDNA was centrifuged at high speed at 4° C for 15 minutes. The resulting pellet was washed with 70% ethanol and then dried at room temperature, and then was dissolved in 20 μl of water.

The foregoing procedure produced purified cDNA which was used as a template to carry out first round PCR using primers #22 and oligo-dT for cloning OMT cDNA and primer R1S and R2A for

cloning 4CL cDNA. For the first round PCR, a master mix of 50μl for each reaction was prepared. Each 50μl mixture contained:

a. 10x buffer 5μl
b. 25 mM $MgCl_2$ 5μl
c. 100 μM sense primer 1μl (primer #22 for OMT and primer R1S for CCL).
d. 100 μl anti-sense primer 1 μl (oligo-dT primer for OMT and R2A for CCL).
e. 10 mM dNTP 1 μl
f. Taq. DNA polymerase 0.5 μl

Of this master mix, 48 μl was added into a PCR tube containing 2 μl of cDNA for PCR. The tube was heated to 95° C for 45 seconds, 52°C for one minute and 72° C for two minutes. This temperature cycle was repeated for 40 cycles and the mixture was then held at 72° C for 10 minutes.

The cDNA fragments obtained from the first round of PCR were used as templates to perform the second round of PCR using primers 22 and 23 for cloning bi-OMT cDNA and primer H1S and R2A for cloning 4CL cDNA. The second round of PCR conditions were the same as the first round.

The desired cDNA fragment was then sub-cloned and sequenced. After the second round of PCR, the product with the predicted size was excised from the gel and ligated into a pUC19 vector, available from Clonetech, of Palo Alto, CA, and then transformed into DH5α, an *E. coli* strain , available from Gibco BRL, of Gaithersburg, MD. After the inserts had been checked for correct size, the colonies were isolated and plasmids were sequenced using a Sequenase kit available from USB, of Cleveland, OH. The sequences are shown in Fig. 2 (SEQ ID 5 and 6) and Fig. 3 (SEQ ID 7 and 8).

Example 2 - Alternative Isolation Method of Angiosperm bi-OMT gene

As previously mentioned, one bi-OMT clone was produced via modified differential display technique. This method is another type of reverse transcription-PCR, in which DNA-free total RNA was reverse transcribed using oligo-dT primers with a single base pair anchor to form cDNA. The oligo-dT primers used for reverse transcription of mRNA to synthesize cDNA were:

T11A: TTTTTTTTTTTA,

T11C: TTTTTTTTTTTC, and

T11G: TTTTTTTTTTTG,

These cDNAs were then used as templates for radioactive PCR which was conducted in the presence of the same oligo-dT primers as listed above, a bi-OMT gene-specific primer and 35S-dATP. The OMT gene-specific primer was derived from the following amino acid sequence: 5'-Cys Cys Asn Gly Gly Asn Gly Gly Ser Ala Arg Gly Ala-3'.

The following PCR reaction solutions were combined in a microfuge tube:

a. H_2O 9.2μl,
b. Taq Buffer 2.0μl
c. dNTP (25μM) 1.6μl

d. Primers (5 μM) 2 μl. for each primer
e. ^{35}S-dATP 1μl
f. Taq. pol. 0.2μl
g. cDNA 2.0μl.

The tube was heated to a temperature of 94° C and held for 45 seconds, then at 37° C for 2 minutes and then 72°C for 45 seconds for forty cycles, followed by a final reaction at 72°C for 5 minutes.

The amplified products were fractionated on a denaturing polyacrylamide sequencing gel and autoradiography was used to identify and excise the fragments with a predicted size. The designed OMT gene-specific primer had a sequence conserved in a region toward the 3'-end of the OMT cDNA sequence. This primer, together with oligo-dT, was amplified into a OMT cDNA fragment of about 300 bp.

Three oligo-dTs with a single base pair of A, C or G, respectively, were used to pair with the OMT gene-specific primer. Eight potential OMT cDNA fragments with predicted sizes of about 300 bp were excised from the gels after several independent PCR rounds using different combinations of oligo-dT and OMT gene-specific oligo-nucleotides as primers.

The OMT cDNA fragments were then re-amplified. A Southern blot analysis was performed for the resulting cDNAs using a 360 base-pair, ^{32}P radio-isotope labeled, aspen OMT cDNA 3'-end fragment as a probe to identify the cDNA fragments having a strong hybridization signal, under low stringency conditions. Eight fragments were identified. Out of these eight cDNA fragments, three were selected based on their high hybridization signal for sub-cloning and sequencing. One clone, LsOMT3'-1, (where the "Ls" prefix indicates that the clone was derived from the Liquidambar styraciflua (L.) genome) was confirmed to encode bi-OMT based on its high homology to other lignin-specific plant OMTs at both nucleotide and amino acid sequence levels.

A cDNA library was constructed in Lambda ZAP II, available from Stratagene, of LaJolla, CA, using 5μg poly(A)+RNA isolated from sweetgum xylem tissue. The primary library consisting of approximately 0.7 x 10^6 independent recombinants was amplified and approximately 10^5 plaque-forming-units (pfu) were screened using a homologous 550 base-pair probe. The hybridized filter was washed at high stringency (0.25 x SSC, 0.1% SDS, 65° C) conditions. The colony containing the bi-OMT fragment identified by the probe was eluted and the bi-OMT fragment was produced. The sequence as illustrated in Fig. 2 (SEQ ID 5 and 6) was obtained.

Example 3 - Isolating and Producing the DNA which codes for the Angiosperm P450-1 Gene

In order to find putative P450 cDNA fragments as probes for cDNA library screening, a highly degenerated sense primer based on the amino acid sequence of 5'-Glu, Glu, Phe, Arg, Pro, Glu, Arg-3' was designed based on the conserved regions found in some plant P450 proteins. This conserved domain was located upstream of another highly conserved region in P450 proteins, which had an amino

acid sequence of 5'-Phe Gly Xaa Gly Xaa Xaa Cys Xaa Gly-3'. This primer was synthesized with the incorporation of an XboI restriction site to give a 26-base-pair oligomer.

This primer and the oligo-dT-XhoI primer were then used to perform PCR reactions with the sweetgum cDNA library as a template. The cDNA library was constructed in Lambda ZAPII, available from Stratagene, of LaJolla, CA, using poly(A) +RNA isolated from Sweetgum xylem tissue. Amplified fragments of 300 to 600 bp were obtained. Because the designed primer was located upstream of the highly conserved P450 domain, this design distinguished whether the PCR products were P450 gene fragments depending on whether they contained the highly conserved amino acid domain.

All the fragments obtained from the PCR reaction were then cloned into a pUC19 vector, available from New England Biolab, Beverly, MA, and transformed into a DH5α *E. coli* strain, available from Gibco BRL, of Gaithersburg, MD.

Twenty-four positive colonies were obtained and sequenced. Sequence analysis indicated four groupings within the twenty-four colonies. One was C4H, one was an unknown P450 gene, and two did not belong to P450 genes. Homologies of P450 genes in different species are usually more than 80%. Because the homologies between the P450 gene families found here were around 40%, the sequence analysis indicated that a new P450 gene family was sequenced. Moreover, since this P450 cDNA was isolated from xylem tissue, it was highly probable that this P450 gene was P450-1.

The novel sweetgum P450 cDNA fragment was used as a probe to screen a full length cDNA encoding for P450-1. Once the P450-1 gene was located it was sequenced. The length of the P450-1 cDNA is 1707 bp and it contains 45 bp of 5' non-coding region and 135 bp of 3' non-coding region. The deduced amino acid sequence also indicates that this P450 cDNA has a hydrophobic core at the N-terminal, which could be regarded as a leader sequence for c-translational targeting to membranes during protein synthesis. At the C-terminal region, there is a heme binding domain that is characteristic of all P450 genes. The P450-1 sequence, as illustrated in Fig. 4 (SEQ ID 1 and 2), was produced, according to the above described methods.

Example 4 - Isolating and Producing the DNA which codes for the Angiosperm P450-2 Gene

By using similar strategy of synthesizing PCR primers from the published literature for hydroxylase genes in plants, another full length P450 cDNA has been isolated that shows significant similarity with a putitive F5H clone from Arabidopsis (Meyers et al. 1996: PNAS 93, 6869-6874). This cloned cDNA, designated P450-2, contains 1883 bp and encodes an open reading frame of 511 amino acids. The amino acid similarity shared between Arabidopsis F5H and the P450-2 sweetgum clone is about 75%.

To confirm the function of the FA5H-2 gene, it was expressed in *E.coli*, strain, DH5 alpha, via pQE vector preparation, according to directions available with the kit. A CO-Fe^{2+} binding assay was

also performed to confirm the expression of P450-2 as a functional P450 gene. (Omura & Sato 1964, J. of Biochemistry 239: 2370-2378, Babriac et.al. 1991 Archives of Biochemistry and Biophysics 288:302-309). The CO-Fe^{2+} binding assay showed a peak at 450nm which indicates that P450-2 has been overexpressed as a functional P450 gene.

The P450-2 protein was further purified for production of antibodies in rabbits, and antibodies have been successfully produced. In addition, Western blots show that this antibody is specific to the membrane fraction of sweetgum and aspen xylem extract. When the P450-2 antibody was added to a reaction mixture containing aspen xylem tissue, enzyme inhibition studies showed that the activity of FA5H in aspen was reduced more than 60%, a further indication that P450-2 performs a P450-like function. Recombinant P450-2 protein co-expressed with Arabidopsis CPR protein in a baculovirus expression system hydroxylated ferulic acid (specific activity: 7.3 pKat/mg protein), cinnamic acid (specific activity: 25 pKat/mg protein), and p-coumaric acid (specific activity: 3.8 pKat/mg protein). The P450-2 enzyme which may be referred to as C4C3F5-H appears to be a broad spectrum hydroxylase in the phenylproponoid pathway in plants. Fig. 5 (SEQ ID 3 and 4) illustrates the P450-2 sequence.

Example 5 - Identifying Gymnosperm Promoter Regions

In order to identify gymnosperm promoter regions, sequences from loblolly pine PAL and 4CL1B and 4CL3B lignin genes were used as primers to screen the loblolly pine genomic library, using the GenomeWalker Kit. The loblolly pine PAL primer sequence was obtained from the GenBank, reference number U39792. The loblolly pine 4CL1B primer sequences were also obtained from the gene bank, reference numbers U39404 and U39405.

The loblolly pine genomic library was constructed in Lambda DashII, available from Stratagene, of LaJolla, CA. 3 x 10^6 phage plaques from the genomic library of loblolly pine were screened using both the above mentioned PAL cDNA and 4CL (PCR clone) fragments as probes. Five 4CL clones were obtained after screening. Lambda DNAs of two 4CL of the five 4CL clones obtained after screening were isolated and digested by EcoRV, PstI, SalI and XbaI for Southern analysis. Southern analysis using 4CL fragments as probes indicated that both clones for the 4CL gene were identical. Results from further mapping showed that none of the original five 4CL clones contained promoter regions. When tested, the PAL clones obtained from the screening also did not contain promoter regions.

In a second attempt to clone the promoter regions associated with the PAL and 4CL a Universal GenomeWalker(TM) kit, available from Clontech, was used. In the process, total DNA from loblolly pine was digested by several restriction enzymes and ligated into the adaptors (libraries) provided with the kit. Two gene-specific primers for each gene were designed (GSP1 and 2). After two rounds of PCR using these primers and adapter primers of the kit, several fragments were amplified from each

library. A 1.6 kb fragment and a 0.6 kb fragment for PAL gene and a 2.3 kb fragment (4CL1B) and a 0.7 kb fragment (4CL3B) for the 4CL gene were cloned, sequenced and found to contain promoter regions for all three genes. See Fig. 6 (SEQ ID 10), 7 (SEQ ID 11) and 8 (SEQ ID 9).

Example 6 - Fusing the ASL DNA Sequence to A Constitutive Promoter Region and Inserting the Expression Cassette Into a Gymnosperm Genome

As a first step, a ASL DNA sequence, P450-1, was fused with a constitutive promoter region according to the methods described in the above Section IV to form an P450-1 expression cassette. A second ASL DNA sequence, P450-2, was then fused with a constitutive promoter in the same manner to form a P450-2 expression cassette. The P450-1 expression cassette was inserted into the gymnosperm genome by micro-projectile bombardment. Embryogenic tissue cultures of loblolly pine were initiated from immature zygotic embryos. The tissue was maintained in an undifferentiated state on semi-solid proliferation medium, according to methods described by Newton et al. TAES Technical Publication "Somatic Embryogenesis in Slash Pine", 1995 and Keinonen-Mettala et al. 1996, Scand. J. For. Res. 11: 242-250.

After separation, 5 ml of the liquid cell suspension fraction which passes through the 40 mesh screen was vacuum deposited onto filter paper and placed on semi-solid proliferation medium. The prepared gymnosperm target cells were then grown for 2 days on filter paper discs placed on semi-solid proliferation medium in a petri dish. These target cells were then bombarded with plasmid DNA containing the P450-1 expression cassette and an expression cassette containing a selectable marker gene encoding the enzyme which confers resistance to the antibiotic hygromycin B. A 1:1 mixture of of selectable marker expression cassette and plasmid DNA containing the P450-1 expression cassette is precipitated with gold (1.5-3.0 microns) as described by Sanford et al. (1992). The DNA-coated microprojectiles were rinsed in absolute ethanol and aliquots of 10 μl (5 μg DNA/3mg gold) were dried onto a macrocarrier, such as those available from BioRad (Hercules, CA).

Prior to bombardment, embryogenic tissue was desiccated under a sterile laminar-flow hood for 5 minutes. The desiccated tissue was transferred to semi-solid proliferation medium. The microprojectiles were accelerated into desiccated target cells using a BioRad PDS-1000/HE particle gun.

Each plate was bombarded once, rotated 180 degrees, and bombarded a second time. Preferred bombardment parameters were 1350 psi rupture disc pressure, 6 mm distance from the rupture disc to macrocarrier (gap distance), 1 cm macrocarrier travel distance, and 10 cm distance from macrocarrier stopping screen to culture plate (microcarrier travel distance). Tissue was then transferred to semi-solid proliferation medium containing hygromycin B for two days after bombardment.

The P450-2 expression cassette was inserted into the gymnosperm genome according to the same procedures.

Example 7 - Selecting Transformed Target Cells

After insertion of the P450-2 expression cassette and the selectable marker expression cassette into the gymnosperm target cells as described in Example 6, transformed cells were selected by exposure to an antibiotic that causes mortality of any cells not containing the GSL expression cassette. Forty independent cell lines were established from cultures co-bombarded with an expression cassette containing a hygromycin resistance gene construct and the P450-1 construct. These cell lines include lines Y2, Y17, Y7 and O4, as discussed in more detail below.

PCR techniques were then used to verify that the P450-1 gene had been successfully integrated into the genomes of the established cell lines by extracting genomic DNA using the Plant DNAeasy kit, available from Qiagen. 200 ng DNA from each cell line were used for each PCR reaction. Two P450-1 specific primers were designed to perform a PCR reaction with a 600bp PCR product size. The primers were:

LsP450-im1-S primer: ATGGCTTTCCTTCTAATACCCATCTC , and

LsP450-im1-A primer: GGGTGTAATGGACGAGCAAGGACTTG.

Each PCR reaction (100 μl) consisted of 75 μl H_2O, 1 μl $MgCl_2$ (25 mM), 10 μl PCR buffer 1 μl 10mM dNTPs, and 10 μl DNA. 100 μl oil was layered on the top of each reaction mix. Hot start PCR was done as follows: PCR reaction was incubated at 95 degrees C for 7 minutes and 1 μl each of both LsP450-im1-S and LsP450-im1-A primers (100 μM stock) and 1 μl of Taq polymerase were added through oil in each reaction. The PCR program used was 95 degrees C for 1.5 minutes, 55 degrees C for 45 seconds and 72 degrees C for 2 minutes, repeated for 40 cycles, followed by extension at 72 degrees C for 10 minutes.

The above PCR products were employed to determine if gymnosperm cells contained the angiosperm lignin gene sequences. With reference to Fig. 9, PCR amplification was performed using template DNA from cells which grew vigorously on hygromycin B-containing medium. The PCR products were electrophoresed in an agarose gel containing 9 lanes. Lanes 1-4 contained PCR amplification of products of the Sweetgum P450-1 gene from a non-transformed control and transgenic loblolly pine cell lines. Lane 1 contained the non-transformed control PT52. Lane 2 contained transgenic line Y2. Lane 3 contained transgenic line Y17 and Lane 4 contained the plasmid which contains the expression cassette pSSLsP450-1-im-s. Lanes 2 through 4 all contain an amplified fragment of about 600 bp, indicating that the P450-1 gene has been successfully inserted into transgenic cell lines Y2 and Y17.

Lane 5 contained a DNA size marker Phi 174/HaeIII (BRL). The top four bands in this lane indicate molecular sizes of 1353, 1078, 872 and 603 bp.

Lanes 6-9 contained PCR amplification products of hygromycin B gene from non-transformed control and transgenic loblolly pine cell lines. Lane 6 contained the non-transformed control line

referenced to as PT52. Lane 7 contained transgenic line Y7. Lane 8 contained transgenic line O4. Lane 9 contained the plasmid which includes the expression cassette containing the gene encoding the enzyme which confers resistance to the antibiotic hygromycin B. Lanes 7-9 all show an amplified fragment of about 1000bp, indicating that the hygromycin gene has been successfully inserted into transgenic lines Y7 and O4.

These PCR results confirmed the presence of P450-1 and hygromycin resistance gene in transformed loblolly pine cell cultures. The results obtained from the PCR verification of 4 cell lines, and similar tests with the remaining 36 cell lines, confirm stable integration of the P450-1 gene and the hygromycin B gene in 25% of the 40 cell lines.

In addition, loblolly pine embryogenic cells which have been co-bombarded with the P450-2 and hygromycin B expression cassettes, are growing vigorously on hygromycin selection medium, indicating that the P450-2 expression cassette was successfully integrated into the gymnosperm genome.

Although various embodiments and features of the invention have been described in the foregoing detailed description, those of ordinary skill will recognize the invention is capable of numerous modifications, rearrangements and substitutions without departing from the scope of the invention as set forth in the appended claims. For example, in the case where the lignin DNA sequence is transcribed and translated to produce a functional syringyl lignin gene, those of ordinary skill will recognize that because of codon degeneracy a number of polynucleotide sequences will encode the same gene. These variants are intended to be covered by the DNA sequences disclosed and claimed herein. In addition, the sequences claimed herein include those sequences with encode a gene having substantial functional identity with those claimed. Thus, in the case of syringyl lignin genes, for example, the DNA sequences include variant polynucleotide sequences encoding polypeptides which have substantial identity with the amino acid sequence of syringyl lignin and which show syringyl lignin activity in gymnosperms.

What is claimed is:

1. A method for modifying the genome of a gymnosperm which comprises cloning one or more angiosperm DNA sequences which code for genes necessary for production of angiosperm syringyl lignin monomer units, fusing one or more of the angiosperm DNA sequences to a promoter region associated with a gene to form an expression cassette and inserting the expression cassette into the gymnosperm genome to thereby produce a modified genome in the gymnosperm containing genes which code for enzymes which produce syringyl lignin monomer units.

2. The method of claim 1, further comprising incorporating a genetic sequence which codes for anti-sense mRNA into the gymnosperm genome in order to suppress formation of guaiacyl lignin monomer units.

3. A gymnosperm plant containing an expression cassette produced according to the method of claim 1.

4. A loblolly pine containing an expression cassette produced according to the method of claim 1.

5. The method of claim 1 wherein the angiosperm DNA sequences are selected from the class consisting of 4-coumarate CoA ligase (4CL), bifunctional-O-methyl transferase (bi-OMT) and P450-1 and P450-2.

6. The method of claim 1 wherein the promoter region is selected from the class consisting of the 5' flanking region of phenylalanine ammonia-lyase (PAL) and the 5' flanking region of 4-coumarate CoA ligase (4CL1B and 4CL3B).

7. The method of claim 1 wherein the expression cassette is inserted into the gymnosperm genome by way of the transformation vector Agrobacterium.

8. The method of claim 7 wherein the Agrobacterium is *Agrobacterium tumefaciens* EH101.

9. The method of claim 1 wherein the expression cassette is inserted into the gymnosperm genome via direct DNA delivery to a target cell.

10. The method of claim 1 wherein the expression cassette is inserted into the gymnosperm genome by micro-projectile bombardment of a gymnosperm cell.

11. The method of claim 1 wherein the expression cassette is inserted into the gymnosperm genome by electroporation of a gymnosperm cell.

12. The method of claim 1 wherein the expression cassette is inserted into the

gymnosperm genome via silicon carbide whiskers.

13. The method of claim 1 wherein the expression cassette is inserted into the gymnosperm genome via transformed protoplast.

14. The method of claim 1 further comprising inserting a selectable marker into the expression cassette.

15. The method of claim 14 wherein the selectable marker is selected from the group consisting of kanamycin and hygromycin B.

16. The method of claim 2 wherein the anti-sense mRNA is a gymnosperm genetic sequence which codes for the 4-coumarate CoA ligase (4CL) gene.

17. The method of claim 1 wherein the promoter region is a DNA sequence which includes the 5' flanking region of the gymnosperm loblolly pine PAL gene.

18. The method of claim 1 wherein the promoter region is a DNA sequence which includes the 5' flanking region of the gymnosperm loblolly pine 4CL1B gene.

19. The method of claim 1 wherein the promoter region is a DNA sequence which includes the 5' flanking region of the gymnosperm loblolly pine 4CL3B gene.

20. The method of claim 1 wherein the promoter region includes a constitutive promoter.

21. An isolated P450-1 DNA sequence which encodes an enzyme involved in the biosynthesis of syringyl lignin monomer units, wherein said DNA is as shown in SEQ ID. No. 1 and 2.

22. An isolated P450-2 DNA sequence which encodes an enzyme involved in the biosynthesis of syringyl lignin monomer units, wherein said DNA is as shown in SEQ ID. No. 3 and 4.

23. An isolated bi-OMT DNA sequence which encodes an enzyme involved in the biosynthesis of syringyl lignin monomer units, wherein said DNA is as shown in SEQ ID No. 5 and 6.

24. An isolated 4CL DNA sequence which encodes an enzyme involved in the biosynthesis of syringyl lignin monomer units, wherein said DNA is as shown in SEQ ID No. 7 and 8.

25. An isolated DNA, wherein said DNA encodes for an enzyme involved in the biosynthesis of one or more syringyl lignin monomer units.

26. An isolated DNA sequence which includes the 5' flanking region of the gymnosperm loblolly pine PAL gene, containing the lignin promoter region and regulatory elements for

gymnosperm lignin biosynthesis as shown in SEQ ID No. 9.

27. An isolated DNA sequence which includes the 5' flanking region of the gymnosperm loblolly pine 4CL1B, containing the lignin promoter region and regulatory elements for gymnosperm lignin biosynthesis as shown in SEQ ID No. 10.

28. An isolated DNA sequence which includes the 5' flanking region of gymnosperm loblolly pine 4CL3B, containing the lignin promoter region and regulatory elements for gymnosperm lignin biosynthesis as shown in SEQ ID No. 11.

29. An isolated DNA, wherein said DNA includes the promoter region of a gymnosperm gene involved in lignin biosynthesis.

30. A method for modifying the genome of loblolly pine which comprises cloning one or more angiosperm DNA sequences which code for enzymes necessary for production of syringyl lignin monomer units, fusing one or more of the angiosperm DNA sequences to a promoter region to form an expression cassette, and inserting the expression cassette into the loblolly pine genome to thereby produce a modified genome in the loblolly pine containing genes which code for enzymes which produce syringyl lignin monomer units.

31. The method of claim 30 wherein the promoter region is a constitutive promoter.

32. A loblolly pine containing an expression cassette produced according to claim 30.

33. The method of claim 30 wherein the angiosperm DNA sequence is selected from the class consisting of 4-coumarate CoA ligase (4CL), bifunctional-O-methyl transferase (bi-OMT) and P450-1 and P450-2.

34. A loblolly pine containing one or more of the DNA sequences of claim 33.

35. A loblolly pine containing the angiosperm DNA sequence inserted by the method of claim 30.

36. A method for modifying the genome of loblolly pine which comprises cloning the sweetgum P450-1 gene, fusing it to a constitutive promoter to form an expression cassette, and inserting the expression cassette into the loblolly pine genome.

37. A loblolly pine containing the P450-1 gene.

38. A method for modifying the genome of loblolly pine which comprises cloning the sweetgum P450-2 gene, fusing it to a constitutive promoter to form an expression cassette, and inserting the expression cassette into the loblolly pine genome.

39. A loblolly pine containing the P450-2 gene.

40. A method for modifying the genome of a gymnosperm which comprises cloning the

sweetgum P450-1 gene. fusing it to a constitutive promoter to form an expression cassette. and inserting the expression cassette into the gymnosperm genome.

41. A method for modifying the genome of a gymnosperm which comprises cloning the sweetgum P450-2 gene. fusing it to a consititutive promoter to form an expression cassette. and inserting the expression cassette into a gymnosperm genome.

42. A gymnosperm containing the P450-1 gene.

43. A gymnosperm containing the P450-2 gene.

44. A gymnosperm containing a DNA sequence selected from the class consisting of the P450-1 DNA sequence of SEQ ID No. 1 and 2, the P450-2 DNA sequence of SEQ ID No. 3 and 4, the bi-OMT DNA sequence of SEQ ID No. 5 and 6, and the 4CL DNA sequences of SEQ ID No. 7 and 8.

45. The gymnosperm of Claim 38. further comprising syringyl lignin.

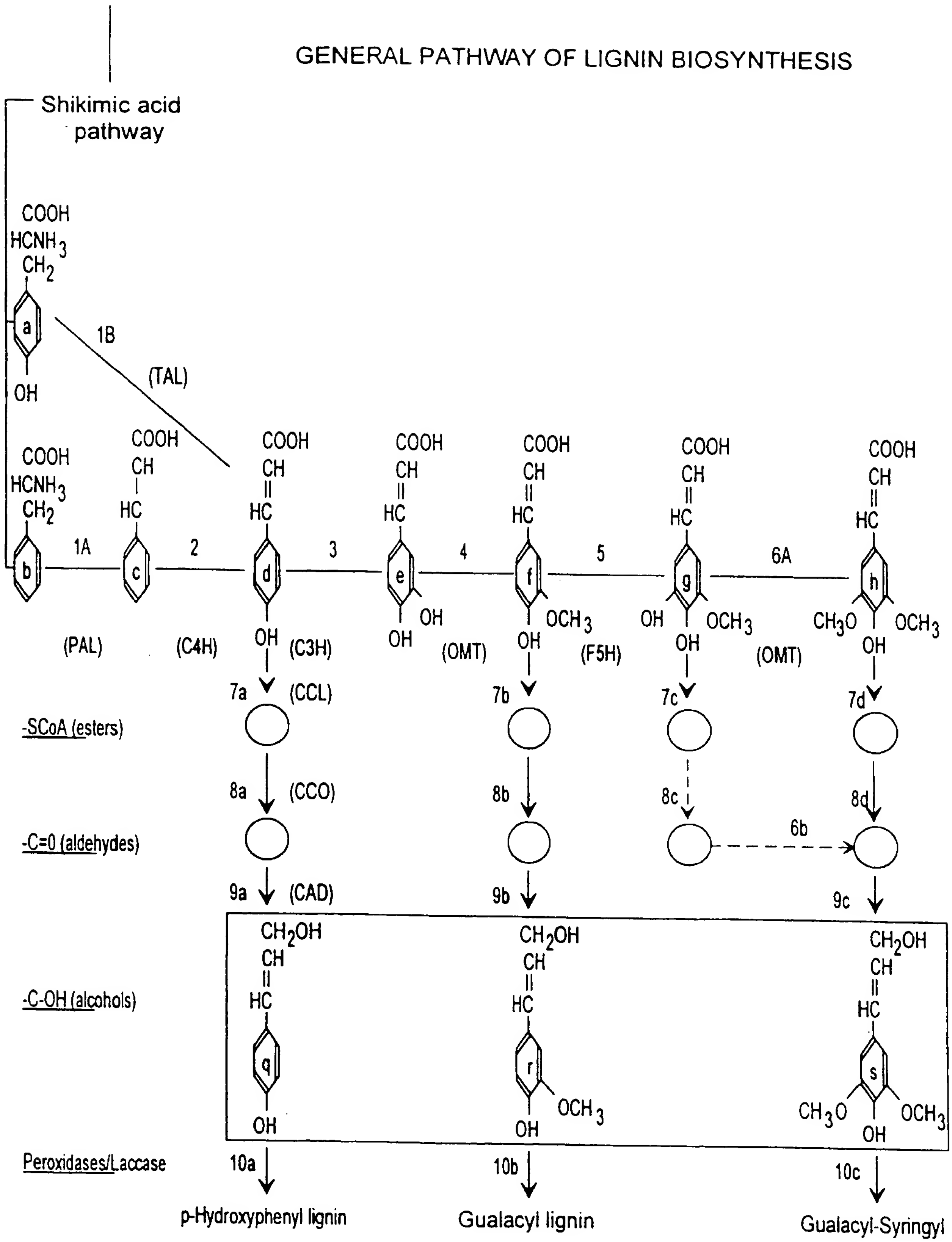
GENERAL PATHWAY OF LIGNIN BIOSYNTHESIS
Shikimic acid pathway
COOH
HCNH3
CH2
a
OH
1B
(TAL)
b
1A
(PAL)
c
2
(C4H)
d
3
(C3H)
e
4
(OMT)
f
5
(F5H)
g
6A
(OMT)
h
OCH3
CH3O
7a
(CCL)
7b
7c
7d
-SCoA (esters)
8a
(CCO)
8b
8c
8d
6b
-C=0 (aldehydes)
9a
(CAD)
9b
9c
-C-OH (alcohols)
CH2OH
q
r
s
Peroxidases/Laccase
10a
10b
10c
p-Hydroxyphenyl lignin
Gualacyl lignin
Gualacyl-Syringyl

FIG. 1

SEQ ID 5

```
<400> 5
cggcacgagc cctacctcct ttcttggaaa aatttcccca ttcgatcaca atccgggcct 60

caaaaa atg gga tca aca agc gaa acg aag atg agc ccg agt gaa gca     108
       Met Gly Ser Thr Ser Glu Thr Lys Met Ser Pro Ser Glu Ala
         1               5                  10

gca gca gca gaa gaa gaa gca ttc gta ttc gct atg caa tta acc agt     156
Ala Ala Ala Glu Glu Glu Ala Phe Val Phe Ala Met Gln Leu Thr Ser
 15                  20                  25                  30

gct tca gtt ctt ccc atg gtc cta aaa tca gcc ata gag ctc gac gtc     204
Ala Ser Val Leu Pro Met Val Leu Lys Ser Ala Ile Glu Leu Asp Val
                 35                  40                  45

tta gaa atc atg gct aaa gct ggt cca ggt gcg cac ata tcc aca tct     252
Leu Glu Ile Met Ala Lys Ala Gly Pro Gly Ala His Ile Ser Thr Ser
             50                  55                  60

gac ata gcc tct aag ctg ccc aca aag aat cca gat gca gcc gtc atg     300
Asp Ile Ala Ser Lys Leu Pro Thr Lys Asn Pro Asp Ala Ala Val Met
         65                  70                  75

ctt gac cgt atg ctc cgc ctc ttg gct agc tac tct gtt cta acg tgc     348
Leu Asp Arg Met Leu Arg Leu Leu Ala Ser Tyr Ser Val Leu Thr Cys
     80                  85                  90

tct ctc cgc acc ctc cct gac ggc aag atc gag agg ctt tac ggc ctt     396
Ser Leu Arg Thr Leu Pro Asp Gly Lys Ile Glu Arg Leu Tyr Gly Leu
 95                 100                 105                 110

gca ccc gtt tgt aaa ttc ttg acc aga aac gat gat gga gtc tcc ata     444
Ala Pro Val Cys Lys Phe Leu Thr Arg Asn Asp Asp Gly Val Ser Ile
                115                 120                 125

gcc gct ctg tct ctc atg aat caa gac aag gtc ctc atg gag agc tgg     492
Ala Ala Leu Ser Leu Met Asn Gln Asp Lys Val Leu Met Glu Ser Trp
            130                 135                 140

tac cac ttg acc gag gca gtt ctt gaa ggt gga att cca ttt aac aag     540
Tyr His Leu Thr Glu Ala Val Leu Glu Gly Gly Ile Pro Phe Asn Lys

        145                 150                 155
```

Fig. 2A

SEQ ID 5

gcc tat gga atg aca gca ttt gag tac cat ggc acc gat ccc aga ttc 588
Ala Tyr Gly Met Thr Ala Phe Glu Tyr His Gly Thr Asp Pro Arg Phe
160 165 170

aac aca gtt ttc aac aat gga atg tcc aat cat tcg acc att acc atg 636
Asn Thr Val Phe Asn Asn Gly Met Ser Asn His Ser Thr Ile Thr Met
175 180 185 190

aag aaa atc ctt gag act tac aaa ggg ttc gag gga ctt gga tct gtg 684
Lys Lys Ile Leu Glu Thr Tyr Lys Gly Phe Glu Gly Leu Gly Ser Val
195 200 205

gtt gat gtt ggt ggt ggc act ggt gcc cac ctt aac atg att atc gct 732
Val Asp Val Gly Gly Gly Thr Gly Ala His Leu Asn Met Ile Ile Ala
210 215 220

aaa tac ccc atg atc aag ggc att aac ttc gac ttg cct cat gtt att 780
Lys Tyr Pro Met Ile Lys Gly Ile Asn Phe Asp Leu Pro His Val Ile
225 230 235

gag gag gct ccc tcc tat cct ggt gtg gag cat gtt ggt gga gat atg 828
Glu Glu Ala Pro Ser Tyr Pro Gly Val Glu His Val Gly Gly Asp Met
240 245 250

ttt gtt agt gtt cca aaa gga gat gcc att ttc atg aag tgg ata tgt 876
Phe Val Ser Val Pro Lys Gly Asp Ala Ile Phe Met Lys Trp Ile Cys
255 260 265 270

cat gat tgg agc gat gaa cac tgc ttg aag ttt ttg aag aaa tgt tat 924
His Asp Trp Ser Asp Glu His Cys Leu Lys Phe Leu Lys Lys Cys Tyr
275 280 285

gaa gca ctt cca acc aat ggg aag gtg atc ctt gct gaa tgc atc ctc 972
Glu Ala Leu Pro Thr Asn Gly Lys Val Ile Leu Ala Glu Cys Ile Leu
290 295 300

ccc gtg gcg cca gac gca agc ctc ccc act aag gca gtg gtc cat att 1020
Pro Val Ala Pro Asp Ala Ser Leu Pro Thr Lys Ala Val Val His Ile
305 310 315

gat gtc atc atg ttg gct cat aac cca ggt ggg aaa gag aga act gag 1068
Asp Val Ile Met Leu Ala His Asn Pro Gly Gly Lys Glu Arg Thr Glu
320 325 330

aag gag ttt gag gcc ttg gcc aag ggg gct gga ttt gaa ggt ttc cga 1116
Lys Glu Phe Glu Ala Leu Ala Lys Gly Ala Gly Phe Glu Gly Phe Arg

Fig. 2B

SEQ ID 5

```
335                 340                  345                 350

gta gta gcc tcg tgc gct tac aat aca tgg atc atc gaa ttt ttg aag    1164
Val Val Ala Ser Cys Ala Tyr Asn Thr Trp Ile Ile Glu Phe Leu Lys
                355                  360                 365

aag att tgagtcctta ctcggctttg agtacataat accaactcct tttggttttc     1220
Lys Ile

gagattgtga ttgtgattgt gattgtctct ctttcgcagt tggccttatg atataatgta 1280

tcgttaactc gatcacagaa gtgcaaaaga cagtgaatgt acactgcttt ataaaataaa 1340

aattttaaga ttttgattca tgtaaaaaaa aaaaaaaaaa                        1380
```

Fig. 2C

SEQ ID 6

<400> 6

Met Gly Ser Thr Ser Glu Thr Lys Met Ser Pro Ser Glu Ala Ala Ala
1 5 10 15

Ala Glu Glu Glu Ala Phe Val Phe Ala Met Gln Leu Thr Ser Ala Ser
20 25 30

Val Leu Pro Met Val Leu Lys Ser Ala Ile Glu Leu Asp Val Leu Glu
35 40 45

Ile Met Ala Lys Ala Gly Pro Gly Ala His Ile Ser Thr Ser Asp Ile
50 55 60

Ala Ser Lys Leu Pro Thr Lys Asn Pro Asp Ala Ala Val Met Leu Asp
65 70 75 80

Arg Met Leu Arg Leu Leu Ala Ser Tyr Ser Val Leu Thr Cys Ser Leu
85 90 95

Arg Thr Leu Pro Asp Gly Lys Ile Glu Arg Leu Tyr Gly Leu Ala Pro
100 105 110

Val Cys Lys Phe Leu Thr Arg Asn Asp Asp Gly Val Ser Ile Ala Ala
115 120 125

Leu Ser Leu Met Asn Gln Asp Lys Val Leu Met Glu Ser Trp Tyr His
130 135 140

Leu Thr Glu Ala Val Leu Glu Gly Gly Ile Pro Phe Asn Lys Ala Tyr
145 150 155 160

Gly Met Thr Ala Phe Glu Tyr His Gly Thr Asp Pro Arg Phe Asn Thr
165 170 175

Val Phe Asn Asn Gly Met Ser Asn His Ser Thr Ile Thr Met Lys Lys
180 185 190

Ile Leu Glu Thr Tyr Lys Gly Phe Glu Gly Leu Gly Ser Val Val Asp
195 200 205

Val Gly Gly Gly Thr Gly Ala His Leu Asn Met Ile Ile Ala Lys Tyr
210 215 220

Pro Met Ile Lys Gly Ile Asn Phe Asp Leu Pro His Val Ile Glu Glu
225 230 235 240

Fig. 2D

SEQ ID 6

Ala	Pro	Ser	Tyr	Pro	Gly	Val	Glu	His	Val	Gly	Gly	Asp	Met	Phe	Val
				245					250					255	
Ser	Val	Pro	Lys	Gly	Asp	Ala	Ile	Phe	Met	Lys	Trp	Ile	Cys	His	Asp
			260					265					270		
Trp	Ser	Asp	Glu	His	Cys	Leu	Lys	Phe	Leu	Lys	Lys	Cys	Tyr	Glu	Ala
		275					280					285			
Leu	Pro	Thr	Asn	Gly	Lys	Val	Ile	Leu	Ala	Glu	Cys	Ile	Leu	Pro	Val
	290					295					300				
Ala	Pro	Asp	Ala	Ser	Leu	Pro	Thr	Lys	Ala	Val	Val	His	Ile	Asp	Val
305					310					315					320
Ile	Met	Leu	Ala	His	Asn	Pro	Gly	Gly	Lys	Glu	Arg	Thr	Glu	Lys	Glu
				325					330					335	
Phe	Glu	Ala	Leu	Ala	Lys	Gly	Ala	Gly	Phe	Glu	Gly	Phe	Arg	Val	Val
			340					345					350		
Ala	Ser	Cys	Ala	Tyr	Asn	Thr	Trp	Ile	Ile	Glu	Phe	Leu	Lys	Lys	Ile
		355					360					365			

Fig. 2E

SEQ ID 7

<400> 7
cggcacgagc tcattttcca cttctggttt gatctctgca attcttccat cagtccccta 59

atg gag acc caa aca aaa caa gaa gaa atc ata tat cgg tcg aaa ctc 107
Met Glu Thr Gln Thr Lys Gln Glu Glu Ile Ile Tyr Arg Ser Lys Leu
1 5 10 15

ccc gat atc tac atc ccc aaa cac ctc cct tta cat tcg tat tgt ttc 155
Pro Asp Ile Tyr Ile Pro Lys His Leu Pro Leu His Ser Tyr Cys Phe
20 25 30

gag aac atc tca cag ttc ggc tcc cgc ccc tgt ctg atc aat ggc gca 203
Glu Asn Ile Ser Gln Phe Gly Ser Arg Pro Cys Leu Ile Asn Gly Ala
35 40 45

acg ggc aag tat tac aca tat gct gag gtt gag ctc att gcg cgc aag 251
Thr Gly Lys Tyr Tyr Thr Tyr Ala Glu Val Glu Leu Ile Ala Arg Lys
50 55 60

gtc gca tcc ggc ctc aac aaa ctc ggc gtt cga caa ggt gac atc atc 299
Val Ala Ser Gly Leu Asn Lys Leu Gly Val Arg Gln Gly Asp Ile Ile
65 70 75 80

atg ctt ttg cta ccc aac tcg ccg gag ttc gtg ttt tca att ctc ggc 347
Met Leu Leu Leu Pro Asn Ser Pro Glu Phe Val Phe Ser Ile Leu Gly
85 90 95

gca tcc tac cgc ggg gct gcc gcc acc gcc gca aac ccg ttt tat acc 395
Ala Ser Tyr Arg Gly Ala Ala Ala Thr Ala Ala Asn Pro Phe Tyr Thr
100 105 110

cct gcc gag atc agg aag caa gcc aaa acc tcc aac gcc agg ctt att 443
Pro Ala Glu Ile Arg Lys Gln Ala Lys Thr Ser Asn Ala Arg Leu Ile
115 120 125

atc aca cat gcc tgt tac tat gag aaa gtg aag gac ttg gtg gaa gag 491
Ile Thr His Ala Cys Tyr Tyr Glu Lys Val Lys Asp Leu Val Glu Glu
130 135 140

aac gtt gcc aag atc ata tgt ata gac tca ccc ccg gac ggt tgt ttg 539
Asn Val Ala Lys Ile Ile Cys Ile Asp Ser Pro Pro Asp Gly Cys Leu
145 150 155 160

Fig. 3A

SEQ ID 7

```
cac ttc tcg gag ctg agt gag gcg gac gag aac gac atg ccc aat gta     587
His Phe Ser Glu Leu Ser Glu Ala Asp Glu Asn Asp Met Pro Asn Val
                165                 170                 175

gag att gac ccc gat gat gtg gtg gcg ctg ccg tac tcg tca ggg acg     635
Glu Ile Asp Pro Asp Asp Val Val Ala Leu Pro Tyr Ser Ser Gly Thr
            180                 185                 190

acg ggt tta cca aag ggg gtg atg cta aca cac aag gga caa gtg acg     683
Thr Gly Leu Pro Lys Gly Val Met Leu Thr His Lys Gly Gln Val Thr
        195                 200                 205

agt gtg gcg caa cag gtg gac gga gag aat ccg aac ctg tat ata cat     731
Ser Val Ala Gln Gln Val Asp Gly Glu Asn Pro Asn Leu Tyr Ile His
    210                 215                 220

agc gag gac gtg gtt ctg tgc gtg ttg cct ctg ttt cac atc tac tcg     779
Ser Glu Asp Val Val Leu Cys Val Leu Pro Leu Phe His Ile Tyr Ser
225                 230                 235                 240

atg aac gtc atg ttt tgc ggg tta cga gtt ggt gcg gcg att ctg att     827
Met Asn Val Met Phe Cys Gly Leu Arg Val Gly Ala Ala Ile Leu Ile
                245                 250                 255

atg cag aaa ttt gaa ata tat ggg ttg tta gag ctg gtc aga agt aca     875
Met Gln Lys Phe Glu Ile Tyr Gly Leu Leu Glu Leu Val Arg Ser Thr
            260                 265                 270

ggt gac cat cat gcc tat cgt aca ccc atc gta ttg gca atc tcc aag     923
Gly Asp His His Ala Tyr Arg Thr Pro Ile Val Leu Ala Ile Ser Lys
        275                 280                 285

act ccg gat ctt cac aac tat gat gtg tcc tcc att cgg act gtc atg     971
Thr Pro Asp Leu His Asn Tyr Asp Val Ser Ser Ile Arg Thr Val Met
    290                 295                 300

tca ggt gcg gct cct ctg ggc aag gaa ctt gaa gat tct gtc aga gct     1019
Ser Gly Ala Ala Pro Leu Gly Lys Glu Leu Glu Asp Ser Val Arg Ala
305                 310                 315                 320

aag ttt ccc acc gcc aaa ctt ggt cag gga tat gga atg acg gag gca     1067
Lys Phe Pro Thr Ala Lys Leu Gly Gln Gly Tyr Gly Met Thr Glu Ala
                325                 330                 335

ggg ccc gtg cta gcg atg tgt ttg gca ttt gcc aag gaa ggg ttt gaa     1115
Gly Pro Val Leu Ala Met Cys Leu Ala Phe Ala Lys Glu Gly Phe Glu
            340                 345                 350
```

Fig. 3B

SEQ ID 7

ata aaa tcg ggg gca tct gga act gtt tta agg aac gca cag atg aag 1163
Ile Lys Ser Gly Ala Ser Gly Thr Val Leu Arg Asn Ala Gln Met Lys
355 360 365

att gtg gac cct gaa acc ggt gtc act ctc cct cga aac caa ccc gga 1211
Ile Val Asp Pro Glu Thr Gly Val Thr Leu Pro Arg Asn Gln Pro Gly
370 375 380

gag att tgc att aga gga gac caa atc atg aaa ggt tat ctt aat gat 1259
Glu Ile Cys Ile Arg Gly Asp Gln Ile Met Lys Gly Tyr Leu Asn Asp
385 390 395 400

cct gag gcg acg gag aga acc ata gac aag gaa ggt tgg tta cac aca 1307
Pro Glu Ala Thr Glu Arg Thr Ile Asp Lys Glu Gly Trp Leu His Thr
405 410 415

ggt gat gtg ggc tac atc gac gat gac act gag ctc ttc att gtt gat 1355
Gly Asp Val Gly Tyr Ile Asp Asp Asp Thr Glu Leu Phe Ile Val Asp
420 425 430

cgg ttg aag gaa ctg atc aaa tac aaa ggg ttt cag gtg gca ccc gct 1403
Arg Leu Lys Glu Leu Ile Lys Tyr Lys Gly Phe Gln Val Ala Pro Ala
435 440 445

gag ctt gag gcc atg ctc ctc aac cat ccc aac atc tct gat gct gcc 1451
Glu Leu Glu Ala Met Leu Leu Asn His Pro Asn Ile Ser Asp Ala Ala
450 455 460

gtc gtc cca atg aaa gac gat gaa gct gga gag ctc cct gtg gcg ttt 1499
Val Val Pro Met Lys Asp Asp Glu Ala Gly Glu Leu Pro Val Ala Phe
465 470 475 480

gtt gta aga tca gat ggt tct cag ata tcc gag gct gaa atc agg caa 1547
Val Val Arg Ser Asp Gly Ser Gln Ile Ser Glu Ala Glu Ile Arg Gln
485 490 495

tac atc gca aaa cag gtg gtt ttt tat aaa aga ata cat cgc gta ttt 1595
Tyr Ile Ala Lys Gln Val Val Phe Tyr Lys Arg Ile His Arg Val Phe
500 505 510

ttc gtc gaa gcc att cct aaa gcg ccc tct ggc aaa atc ttg cgg aag 1643
Phe Val Glu Ala Ile Pro Lys Ala Pro Ser Gly Lys Ile Leu Arg Lys
515 520 525

gac ctg aga gcc aaa ttg gcg tct ggt ctt ccc aat taattctcat 1689
Asp Leu Arg Ala Lys Leu Ala Ser Gly Leu Pro Asn
530 535 540

Fig. 3C

SEQ ID 7

tcgctacccct cctttctctt atcatacgcc aacacgaacg aagaggctca attaaacgct 1749
gctcattcga agcggctcaa ttaaagctgc tcattcatgt ccaccgagtg ggcagcctgt 1809
cttgttggga tgttctttca tttgattcag ctgtgagaag ccagaccctc attatttatt 1869
gtgaaattca caagaatgtc tgtaaatcga tgttgtgagt gatgggtttc aaaacacttt 1929
tgacattgtt tacgttgtat ttcctgctgt tgaaaataac tactttgtat gactttttatt 1989
tgggaagata acctttcaaa aaaaaaaaaa aaaaaa 2025

Fig. 3D

SEQ ID 8

<400> 8

Met Glu Thr Gln Thr Lys Gln Glu Glu Ile Ile Tyr Arg Ser Lys Leu
1 5 10 15

Pro Asp Ile Tyr Ile Pro Lys His Leu Pro Leu His Ser Tyr Cys Phe
20 25 30

Glu Asn Ile Ser Gln Phe Gly Ser Arg Pro Cys Leu Ile Asn Gly Ala
35 40 45

Thr Gly Lys Tyr Tyr Thr Tyr Ala Glu Val Glu Leu Ile Ala Arg Lys
50 55 60

Val Ala Ser Gly Leu Asn Lys Leu Gly Val Arg Gln Gly Asp Ile Ile
65 70 75 80

Met Leu Leu Leu Pro Asn Ser Pro Glu Phe Val Phe Ser Ile Leu Gly
85 90 95

Ala Ser Tyr Arg Gly Ala Ala Ala Thr Ala Ala Asn Pro Phe Tyr Thr
100 105 110

Pro Ala Glu Ile Arg Lys Gln Ala Lys Thr Ser Asn Ala Arg Leu Ile
115 120 125

Ile Thr His Ala Cys Tyr Tyr Glu Lys Val Lys Asp Leu Val Glu Glu
130 135 140

Asn Val Ala Lys Ile Ile Cys Ile Asp Ser Pro Pro Asp Gly Cys Leu
145 150 155 160

His Phe Ser Glu Leu Ser Glu Ala Asp Glu Asn Asp Met Pro Asn Val
165 170 175

Glu Ile Asp Pro Asp Asp Val Val Ala Leu Pro Tyr Ser Ser Gly Thr
180 185 190

Thr Gly Leu Pro Lys Gly Val Met Leu Thr His Lys Gly Gln Val Thr
195 200 205

Ser Val Ala Gln Gln Val Asp Gly Glu Asn Pro Asn Leu Tyr Ile His
210 215 220

Ser Glu Asp Val Val Leu Cys Val Leu Pro Leu Phe His Ile Tyr Ser
225 230 235 240

Fig. 3E

SEQ ID 8

```
Met Asn Val Met Phe Cys Gly Leu Arg Val Gly Ala Ala Ile Leu Ile
                245                 250                 255

Met Gln Lys Phe Glu Ile Tyr Gly Leu Leu Glu Leu Val Arg Ser Thr
            260                 265                 270

Gly Asp His His Ala Tyr Arg Thr Pro Ile Val Leu Ala Ile Ser Lys
        275                 280                 285

Thr Pro Asp Leu His Asn Tyr Asp Val Ser Ser Ile Arg Thr Val Met
    290                 295                 300

Ser Gly Ala Ala Pro Leu Gly Lys Glu Leu Glu Asp Ser Val Arg Ala
305                 310                 315                 320

Lys Phe Pro Thr Ala Lys Leu Gly Gln Gly Tyr Gly Met Thr Glu Ala
                325                 330                 335

Gly Pro Val Leu Ala Met Cys Leu Ala Phe Ala Lys Glu Gly Phe Glu
            340                 345                 350

Ile Lys Ser Gly Ala Ser Gly Thr Val Leu Arg Asn Ala Gln Met Lys
        355                 360                 365

Ile Val Asp Pro Glu Thr Gly Val Thr Leu Pro Arg Asn Gln Pro Gly
    370                 375                 380

Glu Ile Cys Ile Arg Gly Asp Gln Ile Met Lys Gly Tyr Leu Asn Asp
385                 390                 395                 400

Pro Glu Ala Thr Glu Arg Thr Ile Asp Lys Glu Gly Trp Leu His Thr
                405                 410                 415

Gly Asp Val Gly Tyr Ile Asp Asp Asp Thr Glu Leu Phe Ile Val Asp
            420                 425                 430

Arg Leu Lys Glu Leu Ile Lys Tyr Lys Gly Phe Gln Val Ala Pro Ala
        435                 440                 445

Glu Leu Glu Ala Met Leu Leu Asn His Pro Asn Ile Ser Asp Ala Ala
    450                 455                 460

Val Val Pro Met Lys Asp Asp Glu Ala Gly Glu Leu Pro Val Ala Phe
465                 470                 475                 480
```

Fig. 3F

SEQ ID 8

Val Val Arg Ser Asp Gly Ser Gln Ile Ser Glu Ala Glu Ile Arg Gln
485 490 495

Tyr Ile Ala Lys Gln Val Val Phe Tyr Lys Arg Ile His Arg Val Phe
500 505 510

Phe Val Glu Ala Ile Pro Lys Ala Pro Ser Gly Lys Ile Leu Arg Lys
515 520 525

Asp Leu Arg Ala Lys Leu Ala Ser Gly Leu Pro Asn
530 535 540

Fig. 3G

SEQ ID 1

```
cggcacgagg aaaccctaaa actcacctct cttacccttt ctcttca atg gct ttc     56
                                                    Met Ala Phe
                                                     1

ctt cta ata ccc atc tca ata atc ttc atc gtc tta gct tac cag ctc    104
Leu Leu Ile Pro Ile Ser Ile Ile Phe Ile Val Leu Ala Tyr Gln Leu
     5                  10                  15

tat caa cgg ctc aga ttt aag ctc cca ccc ggc cca cgt cca tgg ccg    152
Tyr Gln Arg Leu Arg Phe Lys Leu Pro Pro Gly Pro Arg Pro Trp Pro
 20                 25                  30                  35

atc gtc gga aac ctt tac gac ata aaa ccg gtg agg ttc cgg tgt ttc    200
Ile Val Gly Asn Leu Tyr Asp Ile Lys Pro Val Arg Phe Arg Cys Phe
                40                  45                  50

gcc gag tgg tca caa gcg tac ggt ccg atc ata tcg gtg tgg ttc ggt    248
Ala Glu Trp Ser Gln Ala Tyr Gly Pro Ile Ile Ser Val Trp Phe Gly

            55                  60                  65

tca acg ttg aat gtg atc gta tcg aat tcg gaa ttg gct aag gaa gtg    296
Ser Thr Leu Asn Val Ile Val Ser Asn Ser Glu Leu Ala Lys Glu Val
        70                  75                  80

ctc aag gaa aaa gat caa caa ttg gct gat agg cat agg agt aga tca    344
Leu Lys Glu Lys Asp Gln Gln Leu Ala Asp Arg His Arg Ser Arg Ser
    85                  90                  95

gct gcc aaa ttt agc agg gat ggg cag gac ctt ata tgg gct gat tat    392
Ala Ala Lys Phe Ser Arg Asp Gly Gln Asp Leu Ile Trp Ala Asp Tyr
100                 105                 110                 115

gga cct cac tat gtg aag gtt aca aag gtt tgt acc ctc gag ctt ttt    440
Gly Pro His Tyr Val Lys Val Thr Lys Val Cys Thr Leu Glu Leu Phe
                120                 125                 130

act cca aag cgg ctt gaa gct ctt aga ccc att aga gaa gat gaa gtt    488
Thr Pro Lys Arg Leu Glu Ala Leu Arg Pro Ile Arg Glu Asp Glu Val
            135                 140                 145

aca gcc atg gtt gag tcc att ttt aat gac act gcg aat cct gaa aat    536
Thr Ala Met Val Glu Ser Ile Phe Asn Asp Thr Ala Asn Pro Glu Asn
        150                 155                 160
```

Fig. 4A

SEQ ID 1

tat ggg aag agt atg ctg gtg aag aag tat ttg gga gca gta gca ttc 584
Tyr Gly Lys Ser Met Leu Val Lys Lys Tyr Leu Gly Ala Val Ala Phe
165 170 175

aac aac att aca aga ctc gca ttt gga aag cga ttc gtg aat tca gag 632
Asn Asn Ile Thr Arg Leu Ala Phe Gly Lys Arg Phe Val Asn Ser Glu
180 185 190 195

ggt gta atg gac gag caa gga ctt gaa ttt aag gaa att gtg gcc aat 680
Gly Val Met Asp Glu Gln Gly Leu Glu Phe Lys Glu Ile Val Ala Asn
200 205 210

gga ctc aag ctt ggt gcc tca ctt gca atg gct gag cac att cct tgg 728
Gly Leu Lys Leu Gly Ala Ser Leu Ala Met Ala Glu His Ile Pro Trp
215 220 225

ctc cgt tgg atg ttc cca ctt gag gaa ggg gcc ttt gcc aag cat ggg 776
Leu Arg Trp Met Phe Pro Leu Glu Glu Gly Ala Phe Ala Lys His Gly
230 235 240

gca cgt agg gac cga ctt acc aga gct atc atg gaa gag cac aca ata 824
Ala Arg Arg Asp Arg Leu Thr Arg Ala Ile Met Glu Glu His Thr Ile
245 250 255

gcc cgt aaa aag agt ggt gga gcc caa caa cat ttc gtg gat gca ttg 872
Ala Arg Lys Lys Ser Gly Gly Ala Gln Gln His Phe Val Asp Ala Leu
260 265 270 275

ctc acc cta caa gag aaa tat gac ctt agc gag gac act att att ggg 920
Leu Thr Leu Gln Glu Lys Tyr Asp Leu Ser Glu Asp Thr Ile Ile Gly
280 285 290

ctc ctt tgg gat atg atc act gca ggc atg gac aca acc gca atc tct 968
Leu Leu Trp Asp Met Ile Thr Ala Gly Met Asp Thr Thr Ala Ile Ser
295 300 305

gtc gaa tgg gcc atg gcc gag tta att aag aac cca agg gtg caa caa 1016
Val Glu Trp Ala Met Ala Glu Leu Ile Lys Asn Pro Arg Val Gln Gln
310 315 320

aaa gct caa gag gag cta gac aat gta ctt ggg tcc gaa cgt gtc ctg 1064
Lys Ala Gln Glu Glu Leu Asp Asn Val Leu Gly Ser Glu Arg Val Leu
325 330 335

Fig. 4B

SEQ ID 1

acc gaa ttg gac ttc tca agc ctc cct tat cta caa tgt gta gcc aag 1112
Thr Glu Leu Asp Phe Ser Ser Leu Pro Tyr Leu Gln Cys Val Ala Lys
340 345 350 355

gag gca cta agg ctg cac cct cca aca cca cta atg ctc cct cat cgc 1160
Glu Ala Leu Arg Leu His Pro Pro Thr Pro Leu Met Leu Pro His Arg
360 365 370

gcc aat gcc aac gtc aaa att ggt ggc tac gac atc cct aag gga tca 1208
Ala Asn Ala Asn Val Lys Ile Gly Gly Tyr Asp Ile Pro Lys Gly Ser
375 380 385

aat gtt cat gta aat gtc tgg gcc gtg gct cgt gat cca gca gtg tgg 1256
Asn Val His Val Asn Val Trp Ala Val Ala Arg Asp Pro Ala Val Trp
390 395 400

cgt gac cca cta gag ttt cga ccg gaa cgg ttc tct gaa gac gat gtc 1304
Arg Asp Pro Leu Glu Phe Arg Pro Glu Arg Phe Ser Glu Asp Asp Val
405 410 415

gac atg aaa ggt cac gat tat agg cta ctg ccg ttt ggt gca ggg agg 1352
Asp Met Lys Gly His Asp Tyr Arg Leu Leu Pro Phe Gly Ala Gly Arg
420 425 430 435

cgt gtt tgc ccc ggt gca caa ctt ggc atc aat ttg gtc aca tcc atg 1400
Arg Val Cys Pro Gly Ala Gln Leu Gly Ile Asn Leu Val Thr Ser Met
440 445 450

atg ggt cac cta ttg cac cat ttc tat tgg agc cct cct aaa ggt gta 1448
Met Gly His Leu Leu His His Phe Tyr Trp Ser Pro Pro Lys Gly Val
455 460 465

aaa cca gag gag att gac atg tca gag aat cca gga ttg gtc acc tac 1496
Lys Pro Glu Glu Ile Asp Met Ser Glu Asn Pro Gly Leu Val Thr Tyr
470 475 480

atg cga acc ccg gtg caa gct gtt ccc act cca agg ctg cct gct cac 1544
Met Arg Thr Pro Val Gln Ala Val Pro Thr Pro Arg Leu Pro Ala His
485 490 495

ttg tac aaa cgt gta gct gtg gat atg taattcttag tttgttatta 1591
Leu Tyr Lys Arg Val Ala Val Asp Met
500 505

Fig. 4C

SEQ ID 1

ttcatgctct taaggttttg gactttgaac ttatgatgag atttgtaaaa ttccaagtga 1651

tcaaatgaag aaaagaccaa ataaaaaggc ttgacgattt aaaaaaaaaa aaaaaaa 1708

Fig. 4D

SEQ ID 2

Met Ala Phe Leu Leu Ile Pro Ile Ser Ile Ile Phe Ile Val Leu Ala
1 5 10 15

Tyr Gln Leu Tyr Gln Arg Leu Arg Phe Lys Leu Pro Pro Gly Pro Arg
20 25 30

Pro Trp Pro Ile Val Gly Asn Leu Tyr Asp Ile Lys Pro Val Arg Phe
35 40 45

Arg Cys Phe Ala Glu Trp Ser Gln Ala Tyr Gly Pro Ile Ile Ser Val
50 55 60

Trp Phe Gly Ser Thr Leu Asn Val Ile Val Ser Asn Ser Glu Leu Ala
65 70 75 80

Lys Glu Val Leu Lys Glu Lys Asp Gln Gln Leu Ala Asp Arg His Arg
85 90 95

Ser Arg Ser Ala Ala Lys Phe Ser Arg Asp Gly Gln Asp Leu Ile Trp
100 105 110

Ala Asp Tyr Gly Pro His Tyr Val Lys Val Thr Lys Val Cys Thr Leu
115 120 125

Glu Leu Phe Thr Pro Lys Arg Leu Glu Ala Leu Arg Pro Ile Arg Glu
130 135 140

Asp Glu Val Thr Ala Met Val Glu Ser Ile Phe Asn Asp Thr Ala Asn
145 150 155 160

Pro Glu Asn Tyr Gly Lys Ser Met Leu Val Lys Lys Tyr Leu Gly Ala
165 170 175

Val Ala Phe Asn Asn Ile Thr Arg Leu Ala Phe Gly Lys Arg Phe Val
180 185 190

Asn Ser Glu Gly Val Met Asp Glu Gln Gly Leu Glu Phe Lys Glu Ile
195 200 205

Val Ala Asn Gly Leu Lys Leu Gly Ala Ser Leu Ala Met Ala Glu His
210 215 220

Ile Pro Trp Leu Arg Trp Met Phe Pro Leu Glu Glu Gly Ala Phe Ala
225 230 235 240

Fig. 4E

SEQ ID 2

Lys His Gly Ala Arg Arg Asp Arg Leu Thr Arg Ala Ile Met Glu Glu
245 250 255

His Thr Ile Ala Arg Lys Lys Ser Gly Gly Ala Gln Gln His Phe Val
260 265 270

Asp Ala Leu Leu Thr Leu Gln Glu Lys Tyr Asp Leu Ser Glu Asp Thr
275 280 285

Ile Ile Gly Leu Leu Trp Asp Met Ile Thr Ala Gly Met Asp Thr Thr
290 295 300

Ala Ile Ser Val Glu Trp Ala Met Ala Glu Leu Ile Lys Asn Pro Arg
305 310 315 320

Val Gln Gln Lys Ala Gln Glu Glu Leu Asp Asn Val Leu Gly Ser Glu
325 330 335

Arg Val Leu Thr Glu Leu Asp Phe Ser Ser Leu Pro Tyr Leu Gln Cys
340 345 350

Val Ala Lys Glu Ala Leu Arg Leu His Pro Pro Thr Pro Leu Met Leu
355 360 365

Pro His Arg Ala Asn Ala Asn Val Lys Ile Gly Gly Tyr Asp Ile Pro
370 375 380

Lys Gly Ser Asn Val His Val Asn Val Trp Ala Val Ala Arg Asp Pro
385 390 395 400

Ala Val Trp Arg Asp Pro Leu Glu Phe Arg Pro Glu Arg Phe Ser Glu
405 410 415

Asp Asp Val Asp Met Lys Gly His Asp Tyr Arg Leu Leu Pro Phe Gly
420 425 430

Ala Gly Arg Arg Val Cys Pro Gly Ala Gln Leu Gly Ile Asn Leu Val
435 440 445

Thr Ser Met Met Gly His Leu Leu His His Phe Tyr Trp Ser Pro Pro
450 455 460

Lys Gly Val Lys Pro Glu Glu Ile Asp Met Ser Glu Asn Pro Gly Leu
465 470 475 480

Fig. 4F

SEQ ID 2

Val Thr Tyr Met Arg Thr Pro Val Gln Ala Val Pro Thr Pro Arg Leu
485 490 495

Pro Ala His Leu Tyr Lys Arg Val Ala Val Asp Met
500 505

Fig. 4G

SEQ ID 3

<400> 3

```
tgcaaacctg cacaaacaaa gagagagaag aagaaaaagg aagagaggag agagagagag 60

agagagagaa gcc atg gat tct tct ctt cat gaa gcc ttg caa cca cta    109
               Met Asp Ser Ser Leu His Glu Ala Leu Gln Pro Leu
                1               5                  10

ccc atg acg ctg ttc ttc att ata cct ttg cta ctc tta ttg ggc cta   157
Pro Met Thr Leu Phe Phe Ile Ile Pro Leu Leu Leu Leu Leu Gly Leu
        15                  20                  25

gta tct cgg ctt cgc cag aga cta cca tac cca cca ggc cca aaa ggc   205
Val Ser Arg Leu Arg Gln Arg Leu Pro Tyr Pro Pro Gly Pro Lys Gly
    30                  35                  40

tta ccg gtg atc gga aac atg ctc atg atg gat caa ctc act cac cga   253
Leu Pro Val Ile Gly Asn Met Leu Met Met Asp Gln Leu Thr His Arg
45                  50                  55                  60

gga ctc gcc aaa ctc gcc aaa caa tac gc[illegible] ggt cta ttc cac ctc aag   301
Gly Leu Ala Lys Leu Ala Lys Gln Tyr G[illegible] Gly Leu Phe His Leu Lys
                65                  70                  75

atg gga ttc tta cac atg gtg gcc gtt tcc aca ccc gac atg gct cgc   349
Met Gly Phe Leu His Met Val Ala Val Ser Thr Pro Asp Met Ala Arg
            80                  85                  90

caa gtc ctt caa gtc caa gac aac atc ttc tcg aac cgg cca gcc acc   397
Gln Val Leu Gln Val Gln Asp Asn Ile Phe Ser Asn Arg Pro Ala Thr
        95                  100                 105

ata gcc atc agc tac ctc acc tat gac cga gcc gac atg gcc ttc gct   445
Ile Ala Ile Ser Tyr Leu Thr Tyr Asp Arg Ala Asp Met Ala Phe Ala
    110                 115                 120

cac tac ggc ccg ttt tgg cgt cag atg cgt aaa ctc tgc gtc atg aaa   493
His Tyr Gly Pro Phe Trp Arg Gln Met Arg Lys Leu Cys Val Met Lys
125                 130                 135                 140

tta ttt agc cgg aaa cga gcc gag tcg tgg gag tcg gtc cga gac gag   541
Leu Phe Ser Arg Lys Arg Ala Glu Ser Trp Glu Ser Val Arg Asp Glu
                145                 150                 155

gtc gac tcg gca gta cga gtg gtc gcg tcc aat att ggg tcg acg gtg   589
Val Asp Ser Ala Val Arg Val Val Ala Ser Asn Ile Gly Ser Thr Val
            160                 165                 170
```

Fig. 5A

SEQ ID 3

aat atc ggc gag ctg gtt ttt gct ctg acg aag aat att act tac agg 637
Asn Ile Gly Glu Leu Val Phe Ala Leu Thr Lys Asn Ile Thr Tyr Arg
175 180 185

gcg gct ttt ggg acg atc tcg cat gag gac cag gac gag ttc gtg gcc 685
Ala Ala Phe Gly Thr Ile Ser His Glu Asp Gln Asp Glu Phe Val Ala
190 195 200

ata ctg caa gag ttt tcg cag ctg ttt ggt gct ttt aat ata gct gat 733
Ile Leu Gln Glu Phe Ser Gln Leu Phe Gly Ala Phe Asn Ile Ala Asp
205 210 215 220

ttt atc cct tgg ctc aaa tgg gtt cct cag ggg att aac gtc agg ctc 781
Phe Ile Pro Trp Leu Lys Trp Val Pro Gln Gly Ile Asn Val Arg Leu
225 230 235

aac aag gca cga ggg gcg ctt gat ggg ttt att gac aag atc atc gac 829
Asn Lys Ala Arg Gly Ala Leu Asp Gly Phe Ile Asp Lys Ile Ile Asp
240 245 250

gat cat ata cag aag ggg agt aaa aac tcg gag gag gtt gat act gat 877
Asp His Ile Gln Lys Gly Ser Lys Asn Ser Glu Glu Val Asp Thr Asp
255 260 265

atg gta gat gat tta ctt gct ttt tac ggt gag gaa gcc aaa gta agc 925
Met Val Asp Asp Leu Leu Ala Phe Tyr Gly Glu Glu Ala Lys Val Ser
270 275 280

gaa tct gac gat ctt caa aat tcc atc aaa ctc acc aaa gac aac atc 973
Glu Ser Asp Asp Leu Gln Asn Ser Ile Lys Leu Thr Lys Asp Asn Ile
285 290 295 300

aaa gct atc atg gac gta atg ttt gga ggg acc gaa acg gtg gcg tcc 1021
Lys Ala Ile Met Asp Val Met Phe Gly Gly Thr Glu Thr Val Ala Ser
305 310 315

gcg att gaa tgg gcc atg acg gag ctg atg aaa agc cca gaa gat cta 1069
Ala Ile Glu Trp Ala Met Thr Glu Leu Met Lys Ser Pro Glu Asp Leu
320 325 330

aag aag gtc caa caa gaa ctc gcc gtg gtg gtg ggt ctt gac cgg cga 1117
Lys Lys Val Gln Gln Glu Leu Ala Val Val Val Gly Leu Asp Arg Arg
335 340 345

Fig. 5B

SEQ ID 3

```
gtc gaa gag aaa gac ttc gag aag ctc acc tac ttg aaa tgc gta ctg   1165
Val Glu Glu Lys Asp Phe Glu Lys Leu Thr Tyr Leu Lys Cys Val Leu
    350                 355                 360

aag gaa gtc ctt cgc ctc cac cca ccc atc cca ctc ctc ctc cac gag   1213
Lys Glu Val Leu Arg Leu His Pro Pro Ile Pro Leu Leu Leu His Glu
365                 370                 375                 380

act gcc gag gac gcc gag gtc ggc ggc tac tac att ccg gcg aaa tcg   1261
Thr Ala Glu Asp Ala Glu Val Gly Gly Tyr Tyr Ile Pro Ala Lys Ser
                385                 390                 395

cgg gtg atg atc aac gcg tgc gcc atc ggc cgg gac aag aac tcg tgg   1309
Arg Val Met Ile Asn Ala Cys Ala Ile Gly Arg Asp Lys Asn Ser Trp

            400                 405                 410

gcc gac cca gat acg ttt agg ccc tcc agg ttt ctc aaa gac ggt gtg   1357
Ala Asp Pro Asp Thr Phe Arg Pro Ser Arg Phe Leu Lys Asp Gly Val
        415                 420                 425

ccc gat ttc aaa ggg aac aac ttc gag ttc atc cca ttc ggg tca ggt   1405
Pro Asp Phe Lys Gly Asn Asn Phe Glu Phe Ile Pro Phe Gly Ser Gly
    430                 435                 440

cgt cgg tct tgc ccc ggt atg caa ctc gga ctc tac gcg cta gag acg   1453
Arg Arg Ser Cys Pro Gly Met Gln Leu Gly Leu Tyr Ala Leu Glu Thr
445                 450                 455                 460

act gtg gct cac ctc ctt cac tgt ttc acg tgg gag ttg ccg gac ggg   1501
Thr Val Ala His Leu Leu His Cys Phe Thr Trp Glu Leu Pro Asp Gly
                465                 470                 475

atg aaa ccg agt gaa ctc gag atg aat gat gtg ttt gga ctc acc gcg   1549
Met Lys Pro Ser Glu Leu Glu Met Asn Asp Val Phe Gly Leu Thr Ala
            480                 485                 490

cca aga gcg att cga ctc acc gcc gtg ccg agt cca cgc ctt ctc tgt   1597
Pro Arg Ala Ile Arg Leu Thr Ala Val Pro Ser Pro Arg Leu Leu Cys
        495                 500                 505

cct ctc tat tgatcgaatg attgggggag ctttgtggag gggcttttat           1646
Pro Leu Tyr
    510
```

Fig. 5C

SEQ ID 3

```
ggagactcta tatatagatg ggaagtgaaa caacgacagg tgaatgcttg gatttttggt 1706

atatattggg gagggagggg aaaaaaaaaa taatgaaagg aaagaaaaga gagaatttga 1766

atttctcttc ctctgtggat aaaagcctcg tttttaattg tttttatgtg gagatatttg 1826

tgtttgttta tttttatctc tttttttgca ataacactca aaaataaaaa aaaaaaa    1883
```

Fig. 5D

SEQ ID 4

<400> 4

Met Asp Ser Ser Leu His Glu Ala Leu Gln Pro Leu Pro Met Thr Leu
1 5 10 15

Phe Phe Ile Ile Pro Leu Leu Leu Leu Leu Gly Leu Val Ser Arg Leu
20 25 30

Arg Gln Arg Leu Pro Tyr Pro Pro Gly Pro Lys Gly Leu Pro Val Ile
35 40 45

Gly Asn Met Leu Met Met Asp Gln Leu Thr His Arg Gly Leu Ala Lys
50 55 60

Leu Ala Lys Gln Tyr Gly Gly Leu Phe His Leu Lys Met Gly Phe Leu
65 70 75 80

His Met Val Ala Val Ser Thr Pro Asp Met Ala Arg Gln Val Leu Gln
85 90 95

Val Gln Asp Asn Ile Phe Ser Asn Arg Pro Ala Thr Ile Ala Ile Ser
100 105 110

Tyr Leu Thr Tyr Asp Arg Ala Asp Met Ala Phe Ala His Tyr Gly Pro
115 120 125

Phe Trp Arg Gln Met Arg Lys Leu Cys Val Met Lys Leu Phe Ser Arg
130 135 140

Lys Arg Ala Glu Ser Trp Glu Ser Val Arg Asp Glu Val Asp Ser Ala
145 150 155 160

Val Arg Val Val Ala Ser Asn Ile Gly Ser Thr Val Asn Ile Gly Glu
165 170 175

Leu Val Phe Ala Leu Thr Lys Asn Ile Thr Tyr Arg Ala Ala Phe Gly
180 185 190

Thr Ile Ser His Glu Asp Gln Asp Glu Phe Val Ala Ile Leu Gln Glu
195 200 205

Phe Ser Gln Leu Phe Gly Ala Phe Asn Ile Ala Asp Phe Ile Pro Trp
210 215 220

Leu Lys Trp Val Pro Gln Gly Ile Asn Val Arg Leu Asn Lys Ala Arg
225 230 235 240

Fig. 5E

SEQ ID 4

Gly Ala Leu Asp Gly Phe Ile Asp Lys Ile Ile Asp Asp His Ile Gln
245 250 255

Lys Gly Ser Lys Asn Ser Glu Glu Val Asp Thr Asp Met Val Asp Asp
260 265 270

Leu Leu Ala Phe Tyr Gly Glu Glu Ala Lys Val Ser Glu Ser Asp Asp
275 280 285

Leu Gln Asn Ser Ile Lys Leu Thr Lys Asp Asn Ile Lys Ala Ile Met
290 295 300

Asp Val Met Phe Gly Gly Thr Glu Thr Val Ala Ser Ala Ile Glu Trp
305 310 315 320

Ala Met Thr Glu Leu Met Lys Ser Pro Glu Asp Leu Lys Lys Val Gln
325 330 335

Gln Glu Leu Ala Val Val Val Gly Leu Asp Arg Arg Val Glu Glu Lys
340 345 350

Asp Phe Glu Lys Leu Thr Tyr Leu Lys Cys Val Leu Lys Glu Val Leu
355 360 365

Arg Leu His Pro Pro Ile Pro Leu Leu Leu His Glu Thr Ala Glu Asp
370 375 380

Ala Glu Val Gly Gly Tyr Tyr Ile Pro Ala Lys Ser Arg Val Met Ile
385 390 395 400

Asn Ala Cys Ala Ile Gly Arg Asp Lys Asn Ser Trp Ala Asp Pro Asp
405 410 415

Thr Phe Arg Pro Ser Arg Phe Leu Lys Asp Gly Val Pro Asp Phe Lys
420 425 430

Gly Asn Asn Phe Glu Phe Ile Pro Phe Gly Ser Gly Arg Arg Ser Cys
435 440 445

Pro Gly Met Gln Leu Gly Leu Tyr Ala Leu Glu Thr Thr Val Ala His
450 455 460

Leu Leu His Cys Phe Thr Trp Glu Leu Pro Asp Gly Met Lys Pro Ser
465 470 475 480

Fig. 5F

SEQ ID 4

Glu Leu Glu Met Asn Asp Val Phe Gly Leu Thr Ala Pro Arg Ala Ile
485 490 495

Arg Leu Thr Ala Val Pro Ser Pro Arg Leu Leu Cys Pro Leu Tyr
500 505 510

Fig. 5G

SEQ ID 10

<400> 10

aaacaccaat ttaatgggat ttcagatt[illegible]g tatcccatgc tattggctaa ggcatttttc 60

ttattgtaat ctaaccaatt ctaattt[illegible]ca ccctggtgtg aactgactga caaatgcggt 120

ccgaaaacag cgaatgaaat gtctgggtga tcggtcaaac aagcggtggg cgagagagcg 180

cgggtgttgg cctagccggg atgggggtag gtagacggcg tattaccggc gagttgtccg 240

aatggagttt tcggggtagg tagtaacgta gacgtcaatg gaaaaagtca taatctccgt 300

caaaaatcca accgctcctt cacatcgcag agttggtggc cacgggaccc tccacccact 360

cactcaatcg atcgcctgcc gtggttgccc attattcaac catacgccac ttgactcttc 420

accaacaatt ccaggccggc tttctataca atgtactgca caggaaaatc caatataaaa 480

agccggcctc tgcttccttc tcagtagccc ccagctcatt caattcttcc cactgcaggc 540

tacatttgtc agacacgttt tccgccattt ttcgcctgtt tctgcggaga atttgatcag 600

gttcggattg ggattgaatc aattgaaagg tttttatttt cagtatttcg atcgccatg 659

Fig. 6

SEQ ID 11

<400> 11

ggccgggtgg tgacatttat tcataaattc atctcaaaac aagaaggatt tacaaaaata 60

aaagaaaaca aaattttcat ctttaacata attataattg tgttcacaaa attcaaactt 120

aaacccttaa tataaagaat ttctttcaac aatacacttt aatcacaact tctttcaatca 180

caacctcctc caacaaaatt aaaatagatt aataaataaa taaacttaac tatttaaaaa 240

aaaatattat acaaaattta ttaaaacttc aaaataaaca aacttttttat acaaaattca 300

tcaaaacttt aaaataaagc taaacactga aaatgtgagt acatttaaaa ggacgctgat 360

cacaaaaatt ttgaaaacat aaacaaactt gaaactctac cttttaagaa tgagtttgtc 420

gtctcattaa ctcattagtt ttatagttcg aatccaatta acgtatcttt tattttatgg 480

aataagggtg ttttaataag tgattttggg atttttttag taatttattt gtgatatgtt 540

atggagtttt taaaaatata tatatatata tatatttttg ggttgagttt acttaaaatt 600

tggaaaaggt tggtaagaac tataaattga gttgtgaatg agtgttttat ggattttttta 660

agatgttaaa tttatatatg taattaaaat tttattttga ataacaaaaa ttataattgg 720

ataaaaaatt gttttgttaa atttagagta aaaatttcaa aatctaaaat aattaaacac 780

tattattttt aaaaaatttg ttggtaaatt ttatcttata tttaagttaa aatttagaaa 840

aaattaattt taaattaata aacttttgaa gtcaaatatt ccaaatattt tccaaaatat 900

taaatctatt ttgcattcaa aatacaattt aaataataaa acttcatgga atagatta[illegible] 960

caatttgtat aaaaaccaaa aatctcaaat aaaatttaaa ttacaaaaca ttatcaacat 1020

tatgatttca agaaagacaa taaccagttt ccaataaaat aaaaaacctc atggcccgta 1080

attaagatct cattaattaa ttcttatttt ttaatttttt tacatagaaa atatctttat 1140

attgtatcca agaaatatag aatgttctcg tccagggact attaatctcc aaacaagttt 1200

caaaatcatt acattaaagc tcatcatgtc atttgtggat tggaaattat attgtataag 1260

agaaatatag aatgttctcg tctagggact attaatttcc aaacaaattt caaaat[illegible]att 1320

Fig. 7A

SEQ ID 11

```
acattaaagc tcatcatgtc atttgtggat tggaaattag acaaaaaaaa tcccaaatat 1380
ttctctcaat ctcccaaaat atagttcgaa ctccatattt ttggaaattg agaatttttt 1440
tacccaataa tatatttttt tatacatttt agagattttc cagacatatt tgctctggga 1500
tttattggaa tgaaggttga gttataaact ttcagtaatc caagtatctt cggtttttga 1560
agatactaaa tccattatat aataaaaaca cattttaaac accaatttaa tgggatttca 1620
gatttgtatc ccatgctatt ggctaaggca tttttcttat tgtaatctaa ccaattctaa 1680
tttccaccct ggtgtgaact gactgacaaa tgcggtccga aaacagcgaa tgaaatgtct 1740
gggtgatcgg tcaaacaagc ggtgggcgag agagcgcggg tgttggccta gccgggatgg 1800
gggtaggtag acggcgtatt accggcgagt tgtccgaatg gagttttcgg ggtaggtagt 1860
aacgtagacg tcaatggaaa aagtcataat ctccgtcaaa aatccaaccg ctccttcaca 1920
tcgcagagtt ggtggccacg ggaccctcca cccactcact cgatcgcctg ccgtggttgc 1980
ccattattca accatacgcc acttgactct tcaccaacaa ttccaggccg gctttctata 2040
caatgtactg cacaggaaaa tccaatataa aaagccggcc tctgcttcct tctcagtagc 2100
ccccagctca ttcaattctt cccactgcag gctacatttg tcagacacgt tttccgccat 2160
ttttcgcctg tttctgcgga gaatttgatc aggttcggat tgggattgaa tcaattgaaa 2220
ggtttttatt ttcagtattt cgatcgccat g                                2251
```

Fig. 7B

SEQ ID 9

<400> 9

```
aaagataata tatgtgtatg cctactacta cacattgttt tgaagtgtgt aaacatagtg 60
caacactagg aggactcaca atgagcactt gttgacatga aactagctaa atgcccaaca 120
atat[illegible]agtga aagctagtta aactaacccc tttgactttc aagatgatat atttatatcc 180
ctactacgtc ttcctctttt tgtctttctc ttgtgattaa accttccttg aaacaattct 240
caaatgtaaa attaaacctt gaaacttgta gagaccaaac ttccctagga gaaaccacat 300
ttatgacaac atatatacac caacccattg catactataa tattggaatt acctgcagcg 360
aacgaaagaa acgctgtctc accaactcgt gcactacatc ccgaaactta accttcccct 420
gatacagatt gaagagccga aaaaagcgtg catccaaatt tctggtatgg tgaggagccg 480
aaaaacgcgt gcgcctaatt tttttgagat gggccggaaa ataatgcgtg catctaaatt 540
ttcacgtgtc gcgtattggc gaggttgcgc tgaatgtgat cctgtgcgtg agccacattc 600
attccattgg ttgacccgcc ggtaccgcga ggaccgtggg gtctcacaga tacgcggatg 660
gtggatcagc actgagaaga ttagatgatg accaggcggg catttgaagt aaaaacttgg 720
gggtggttgg caagtacgcg acaaagaggg gtagtgcgca aggaagcgag ttggatgcaa 780
ataatattac aaagtgggtt ggtgggcatg agcatcaacc agaatgatgt tgttgctggt 840
tccgtgcaaa ttctgaccag tagtttgaac aatactaccc aacttgtttt tggtaaaaca 900
tgaagtgggt aaggagaatt gaacttacgt ctcatggtaa agggcaaggg caaatgactt 960
aacacatacc tttaactaat aaaaataccc ctaacaaata cgaaaacgaa tgagttatca 1020
cagaccttca actaataaga tagccatcag acccacatct cctgactgac caaaaacaaa 1080
tgacttcaac caactaagat acccatcaaa gctaacccac aacccaattc ctcacttccc 1140
cttaccagac caaccaagca gacctacgcc attaactact ttaggacgtg ggaattgggg 1200
gtgccaccgt tgaagaatgg cactcagggt tggtaatccc tccacgtgta tgtagcagtc 1260
gtttggtgga gacggcgtgt ttgaatgtcc accttccagt ttggagaaca aggaaattgg 1320
```

Fig. 8A

SEQ ID 9

```
gcttatatta ggcctggatc tcttgtttca gagcaggagt agttcaggac aggaactagc 1380
attcaagaat tcaattgccc tgccctgctc tgctctgctt tgctcaactt attgatccct 1440
gctctggttt gttcaatttc ttgacccctg ctgggttctg ctctggtttg cacactttct 1500
cgattatata agtcattttg gatccttgca aggaagagaa tatg                  1544
```

Fig. 8B

SEQUENCE LISTING

<110> Chiang, Vincent L
Carraway, Daniel T
Smeltzer, Richard H

<120> Production of Syringyl Lignin in Gymnosperms

<130> 50617

<140> US 08/991,677
<141> 1997-12-16

<150> US 60/033,381
<151> 1996-12-16

<160> 11

<170> PatentIn Ver. 2.0

<210> 1
<211> 1708
<212> DNA
<213> Liquidambar styraciflua

<220>
<221> CDS
<222> (48)..(1571)

<400> 1

```
cggcacgagg aaaccctaaa actcacctct cttacccttt ctcttca atg gct ttc    56
                                                    Met Ala Phe
                                                     1

ctt cta ata ccc atc tca ata atc ttc atc gtc tta gct tac cag ctc   104
Leu Leu Ile Pro Ile Ser Ile Ile Phe Ile Val Leu Ala Tyr Gln Leu
      5                  10                  15

tat caa cgg ctc aga ttt aag ctc cca ccc ggc cca cgt cca tgg ccg   152
Tyr Gln Arg Leu Arg Phe Lys Leu Pro Pro Gly Pro Arg Pro Trp Pro
 20                  25                  30                  35

atc gtc gga aac ctt tac gac ata aaa ccg gtg agg ttc cgg tgt ttc   200
Ile Val Gly Asn Leu Tyr Asp Ile Lys Pro Val Arg Phe Arg Cys Phe
                 40                  45                  50

gcc gag tgg tca caa gcg tac ggt ccg atc ata tcg gtg tgg ttc ggt   248
Ala Glu Trp Ser Gln Ala Tyr Gly Pro Ile Ile Ser Val Trp Phe Gly
```

55 60 65

tca acg ttg aat gtg atc gta tcg aat tcg gaa ttg gct aag gaa gtg 296
Ser Thr Leu Asn Val Ile Val Ser Asn Ser Glu Leu Ala Lys Glu Val
70 75 80

ctc aag gaa aaa gat caa caa ttg gct gat agg cat agg agt aga tca 344
Leu Lys Glu Lys Asp Gln Gln Leu Ala Asp Arg His Arg Ser Arg Ser
85 90 95

gct gcc aaa ttt agc agg gat ggg cag gac ctt ata tgg gct gat tat 392
Ala Ala Lys Phe Ser Arg Asp Gly Gln Asp Leu Ile Trp Ala Asp Tyr
100 105 110 115

gga cct cac tat gtg aag gtt aca aag gtt tgt acc ctc gag ctt ttt 440
Gly Pro His Tyr Val Lys Val Thr Lys Val Cys Thr Leu Glu Leu Phe
120 125 130

act cca aag cgg ctt gaa gct ctt aga ccc att aga gaa gat gaa gtt 488
Thr Pro Lys Arg Leu Glu Ala Leu Arg Pro Ile Arg Glu Asp Glu Val
135 140 145

aca gcc atg gtt gag tcc att ttt aat gac act gcg aat cct gaa aat 536
Thr Ala Met Val Glu Ser Ile Phe Asn Asp Thr Ala Asn Pro Glu Asn
150 155 160

tat ggg aag agt atg ctg gtg aag aag tat ttg gga gca gta gca ttc 584
Tyr Gly Lys Ser Met Leu Val Lys Lys Tyr Leu Gly Ala Val Ala Phe
165 170 175

aac aac att aca aga ctc gca ttt gga aag cga ttc gtg aat tca gag 632
Asn Asn Ile Thr Arg Leu Ala Phe Gly Lys Arg Phe Val Asn Ser Glu
180 185 190 195

ggt gta atg gac gag caa gga ctt gaa ttt aag gaa att gtg gcc aat 680
Gly Val Met Asp Glu Gln Gly Leu Glu Phe Lys Glu Ile Val Ala Asn
200 205 210

gga ctc aag ctt ggt gcc tca ctt gca atg gct gag cac att cct tgg 728
Gly Leu Lys Leu Gly Ala Ser Leu Ala Met Ala Glu His Ile Pro Trp
215 220 225

ctc cgt tgg atg ttc cca ctt gag gaa ggg gcc ttt gcc aag cat ggg 776
Leu Arg Trp Met Phe Pro Leu Glu Glu Gly Ala Phe Ala Lys His Gly
230 235 240

gca cgt agg gac cga ctt acc aga gct atc atg gaa gag cac aca ata 824
Ala Arg Arg Asp Arg Leu Thr Arg Ala Ile Met Glu Glu His Thr Ile

245 250 255

gcc cgt aaa aag agt ggt gga gcc caa caa cat ttc gtg gat gca ttg 872
Ala Arg Lys Lys Ser Gly Gly Ala Gln Gln His Phe Val Asp Ala Leu
260 265 270 275

ctc acc cta caa gag aaa tat gac ctt agc gag gac act att att ggg 920
Leu Thr Leu Gln Glu Lys Tyr Asp Leu Ser Glu Asp Thr Ile Ile Gly
280 285 290

ctc ctt tgg gat atg atc act gca ggc atg gac aca acc gca atc tct 968
Leu Leu Trp Asp Met Ile Thr Ala Gly Met Asp Thr Thr Ala Ile Ser
295 300 305

gtc gaa tgg gcc atg gcc gag tta att aag aac cca agg gtg caa caa 1016
Val Glu Trp Ala Met Ala Glu Leu Ile Lys Asn Pro Arg Val Gln Gln
310 315 320

aaa gct caa gag gag cta gac aat gta ctt ggg tcc gaa cgt gtc ctg 1064
Lys Ala Gln Glu Glu Leu Asp Asn Val Leu Gly Ser Glu Arg Val Leu
325 330 335

acc gaa ttg gac ttc tca agc ctc cct tat cta caa tgt gta gcc aag 1112
Thr Glu Leu Asp Phe Ser Ser Leu Pro Tyr Leu Gln Cys Val Ala Lys
340 345 350 355

gag gca cta agg ctg cac cct cca aca cca cta atg ctc cct cat cgc 1160
Glu Ala Leu Arg Leu His Pro Pro Thr Pro Leu Met Leu Pro His Arg
360 365 370

gcc aat gcc aac gtc aaa att ggt ggc tac gac atc cct aag gga tca 1208
Ala Asn Ala Asn Val Lys Ile Gly Gly Tyr Asp Ile Pro Lys Gly Ser
375 380 385

aat gtt cat gta aat gtc tgg gcc gtg gct cgt gat cca gca gtg tgg 1256
Asn Val His Val Asn Val Trp Ala Val Ala Arg Asp Pro Ala Val Trp
390 395 400

cgt gac cca cta gag ttt cga ccg gaa cgg ttc tct gaa gac gat gtc 1304
Arg Asp Pro Leu Glu Phe Arg Pro Glu Arg Phe Ser Glu Asp Asp Val
405 410 415

gac atg aaa ggt cac gat tat agg cta ctg ccg ttt ggt gca ggg agg 1352
Asp Met Lys Gly His Asp Tyr Arg Leu Leu Pro Phe Gly Ala Gly Arg
420 425 430 435

cgt gtt tgc ccc ggt gca caa ctt ggc atc aat ttg gtc aca tcc atg 1400
Arg Val Cys Pro Gly Ala Gln Leu Gly Ile Asn Leu Val Thr Ser Met

440 445 450

atg ggt cac cta ttg cac cat ttc tat tgg agc cct cct aaa ggt gta 1448
Met Gly His Leu Leu His His Phe Tyr Trp Ser Pro Pro Lys Gly Val
455 460 465

aaa cca gag gag att gac atg tca gag aat cca gga ttg gtc acc tac 1496
Lys Pro Glu Glu Ile Asp Met Ser Glu Asn Pro Gly Leu Val Thr Tyr
470 475 480

atg cga acc ccg gtg caa gct gtt ccc act cca agg ctg cct gct cac 1544
Met Arg Thr Pro Val Gln Ala Val Pro Thr Pro Arg Leu Pro Ala His
485 490 495

ttg tac aaa cgt gta gct gtg gat atg taattcttag tttgttatta 1591
Leu Tyr Lys Arg Val Ala Val Asp Met
500 505

ttcatgctct taaggttttg gactttgaac ttatgatgag atttgtaaaa ttccaagtga 1651

tcaaatgaag aaaagaccaa ataaaaaggc ttgacgattt aaaaaaaaaa aaaaaaa 1708

<210> 2
<211> 508
<212> PRT
<213> Liquidambar styraciflua

<400> 2
Met Ala Phe Leu Leu Ile Pro Ile Ser Ile Ile Phe Ile Val Leu Ala
1 5 10 15

Tyr Gln Leu Tyr Gln Arg Leu Arg Phe Lys Leu Pro Pro Gly Pro Arg
20 25 30

Pro Trp Pro Ile Val Gly Asn Leu Tyr Asp Ile Lys Pro Val Arg Phe
35 40 45

Arg Cys Phe Ala Glu Trp Ser Gln Ala Tyr Gly Pro Ile Ile Ser Val
50 55 60

Trp Phe Gly Ser Thr Leu Asn Val Ile Val Ser Asn Ser Glu Leu Ala
65 70 75 80

Lys Glu Val Leu Lys Glu Lys Asp Gln Gln Leu Ala Asp Arg His Arg
85 90 95

Ser Arg Ser Ala Ala Lys Phe Ser Arg Asp Gly Gln Asp Leu Ile Trp

100 105 110

Ala Asp Tyr Gly Pro His Tyr Val Lys Val Thr Lys Val Cys Thr Leu
115 120 125

Glu Leu Phe Thr Pro Lys Arg Leu Glu Ala Leu Arg Pro Ile Arg Glu
130 135 140

Asp Glu Val Thr Ala Met Val Glu Ser Ile Phe Asn Asp Thr Ala Asn
145 150 155 160

Pro Glu Asn Tyr Gly Lys Ser Met Leu Val Lys Lys Tyr Leu Gly Ala
165 170 175

Val Ala Phe Asn Asn Ile Thr Arg Leu Ala Phe Gly Lys Arg Phe Val
180 185 190

Asn Ser Glu Gly Val Met Asp Glu Gln Gly Leu Glu Phe Lys Glu Ile
195 200 205

Val Ala Asn Gly Leu Lys Leu Gly Ala Ser Leu Ala Met Ala Glu His
210 215 220

Ile Pro Trp Leu Arg Trp Met Phe Pro Leu Glu Glu Gly Ala Phe Ala
225 230 235 240

Lys His Gly Ala Arg Arg Asp Arg Leu Thr Arg Ala Ile Met Glu Glu
245 250 255

His Thr Ile Ala Arg Lys Lys Ser Gly Gly Ala Gln Gln His Phe Val
260 265 270

Asp Ala Leu Leu Thr Leu Gln Glu Lys Tyr Asp Leu Ser Glu Asp Thr
275 280 285

Ile Ile Gly Leu Leu Trp Asp Met Ile Thr Ala Gly Met Asp Thr Thr
290 295 300

Ala Ile Ser Val Glu Trp Ala Met Ala Glu Leu Ile Lys Asn Pro Arg
305 310 315 320

Val Gln Gln Lys Ala Gln Glu Glu Leu Asp Asn Val Leu Gly Ser Glu
325 330 335

Arg Val Leu Thr Glu Leu Asp Phe Ser Ser Leu Pro Tyr Leu Gln Cys
340 345 350

Val Ala Lys Glu Ala Leu Arg Leu His Pro Pro Thr Pro Leu Met Leu

355 360 365

Pro His Arg Ala Asn Ala Asn Val Lys Ile Gly Gly Tyr Asp Ile Pro
370 375 380

Lys Gly Ser Asn Val His Val Asn Val Trp Ala Val Ala Arg Asp Pro
385 390 395 400

Ala Val Trp Arg Asp Pro Leu Glu Phe Arg Pro Glu Arg Phe Ser Glu
405 410 415

Asp Asp Val Asp Met Lys Gly His Asp Tyr Arg Leu Leu Pro Phe Gly
420 425 430

Ala Gly Arg Arg Val Cys Pro Gly Ala Gln Leu Gly Ile Asn Leu Val
435 440 445

Thr Ser Met Met Gly His Leu Leu His His Phe Tyr Trp Ser Pro Pro
450 455 460

Lys Gly Val Lys Pro Glu Glu Ile Asp Met Ser Glu Asn Pro Gly Leu
465 470 475 480

Val Thr Tyr Met Arg Thr Pro Val Gln Ala Val Pro Thr Pro Arg Leu
485 490 495

Pro Ala His Leu Tyr Lys Arg Val Ala Val Asp Met
500 505

<210> 3
<211> 1883
<212> DNA
<213> Liquidambar styraciflua

<220>
<221> CDS
<222> (74)..(1606)

<400> 3
tgcaaacctg cacaaacaaa gagagagaag aagaaaaagg aagagaggag agagagagag 60

agagagagaa gcc atg gat tct tct ctt cat gaa gcc ttg caa cca cta 109
Met Asp Ser Ser Leu His Glu Ala Leu Gln Pro Leu
1 5 10

ccc atg acg ctg ttc ttc att ata cct ttg cta ctc tta ttg ggc cta 157
Pro Met Thr Leu Phe Phe Ile Ile Pro Leu Leu Leu Leu Leu Gly Leu

```
        15                  20                  25

gta tct cgg ctt cgc cag aga cta cca tac cca cca ggc cca aaa ggc    205
Val Ser Arg Leu Arg Gln Arg Leu Pro Tyr Pro Pro Gly Pro Lys Gly
     30                  35                  40

tta ccg gtg atc gga aac atg ctc atg atg gat caa ctc act cac cga    253
Leu Pro Val Ile Gly Asn Met Leu Met Met Asp Gln Leu Thr His Arg
 45                  50                  55                  60

gga ctc gcc aaa ctc gcc aaa caa tac ggc ggt cta ttc cac ctc aag    301
Gly Leu Ala Lys Leu Ala Lys Gln Tyr Gly Gly Leu Phe His Leu Lys
                 65                  70                  75

atg gga ttc tta cac atg gtg gcc gtt tcc aca ccc gac atg gct cgc    349
Met Gly Phe Leu His Met Val Ala Val Ser Thr Pro Asp Met Ala Arg
             80                  85                  90

caa gtc ctt caa gtc caa gac aac atc ttc tcg aac cgg cca gcc acc    397
Gln Val Leu Gln Val Gln Asp Asn Ile Phe Ser Asn Arg Pro Ala Thr
         95                 100                 105

ata gcc atc agc tac ctc acc tat gac cga gcc gac atg gcc ttc gct    445
Ile Ala Ile Ser Tyr Leu Thr Tyr Asp Arg Ala Asp Met Ala Phe Ala
    110                 115                 120

cac tac ggc ccg ttt tgg cgt cag atg cgt aaa ctc tgc gtc atg aaa    493
His Tyr Gly Pro Phe Trp Arg Gln Met Arg Lys Leu Cys Val Met Lys
125                 130                 135                 140

tta ttt agc cgg aaa cga gcc gag tcg tgg gag tcg gtc cga gac gag    541
Leu Phe Ser Arg Lys Arg Ala Glu Ser Trp Glu Ser Val Arg Asp Glu
                145                 150                 155

gtc gac tcg gca gta cga gtg gtc gcg tcc aat att ggg tcg acg gtg    589
Val Asp Ser Ala Val Arg Val Val Ala Ser Asn Ile Gly Ser Thr Val
            160                 165                 170

aat atc ggc gag ctg gtt ttt gct ctg acg aag aat att act tac agg    637
Asn Ile Gly Glu Leu Val Phe Ala Leu Thr Lys Asn Ile Thr Tyr Arg
        175                 180                 185

gcg gct ttt ggg acg atc tcg cat gag gac cag gac gag ttc gtg gcc    685
Ala Ala Phe Gly Thr Ile Ser His Glu Asp Gln Asp Glu Phe Val Ala
    190                 195                 200

ata ctg caa gag ttt tcg cag ctg ttt ggt gct ttt aat ata gct gat    733
Ile Leu Gln Glu Phe Ser Gln Leu Phe Gly Ala Phe Asn Ile Ala Asp
```

205 210 215 220

ttt atc cct tgg ctc aaa tgg gtt cct cag ggg att aac gtc agg ctc 781
Phe Ile Pro Trp Leu Lys Trp Val Pro Gln Gly Ile Asn Val Arg Leu
225 230 235

aac aag gca cga ggg gcg ctt gat ggg ttt att gac aag atc atc gac 829
Asn Lys Ala Arg Gly Ala Leu Asp Gly Phe Ile Asp Lys Ile Ile Asp
240 245 250

gat cat ata cag aag ggg agt aaa aac tcg gag gag gtt gat act gat 877
Asp His Ile Gln Lys Gly Ser Lys Asn Ser Glu Glu Val Asp Thr Asp
255 260 265

atg gta gat gat tta ctt gct ttt tac ggt gag gaa gcc aaa gta agc 925
Met Val Asp Asp Leu Leu Ala Phe Tyr Gly Glu Glu Ala Lys Val Ser
270 275 280

gaa tct gac gat ctt caa aat tcc atc aaa ctc acc aaa gac aac atc 973
Glu Ser Asp Asp Leu Gln Asn Ser Ile Lys Leu Thr Lys Asp Asn Ile
285 290 295 300

aaa gct atc atg gac gta atg ttt gga ggg acc gaa acg gtg gcg tcc 1021
Lys Ala Ile Met Asp Val Met Phe Gly Gly Thr Glu Thr Val Ala Ser
305 310 315

gcg att gaa tgg gcc atg acg gag ctg atg aaa agc cca gaa gat cta 1069
Ala Ile Glu Trp Ala Met Thr Glu Leu Met Lys Ser Pro Glu Asp Leu
320 325 330

aag aag gtc caa caa gaa ctc gcc gtg gtg gtg ggt ctt gac cgg cga 1117
Lys Lys Val Gln Gln Glu Leu Ala Val Val Val Gly Leu Asp Arg Arg
335 340 345

gtc gaa gag aaa gac ttc gag aag ctc acc tac ttg aaa tgc gta ctg 1165
Val Glu Glu Lys Asp Phe Glu Lys Leu Thr Tyr Leu Lys Cys Val Leu
350 355 360

aag gaa gtc ctt cgc ctc cac cca ccc atc cca ctc ctc ctc cac gag 1213
Lys Glu Val Leu Arg Leu His Pro Pro Ile Pro Leu Leu Leu His Glu
365 370 375 380

act gcc gag gac gcc gag gtc ggc ggc tac tac att ccg gcg aaa tcg 1261
Thr Ala Glu Asp Ala Glu Val Gly Gly Tyr Tyr Ile Pro Ala Lys Ser
385 390 395

cgg gtg atg atc aac gcg tgc gcc atc ggc cgg gac aag aac tcg tgg 1309
Arg Val Met Ile Asn Ala Cys Ala Ile Gly Arg Asp Lys Asn Ser Trp

400 405 410

gcc gac cca gat acg ttt agg ccc tcc agg ttt ctc aaa gac ggt gtg 1357
Ala Asp Pro Asp Thr Phe Arg Pro Ser Arg Phe Leu Lys Asp Gly Val
415 420 425

ccc gat ttc aaa ggg aac aac ttc gag ttc atc cca ttc ggg tca ggt 1405
Pro Asp Phe Lys Gly Asn Asn Phe Glu Phe Ile Pro Phe Gly Ser Gly
430 435 440

cgt cgg tct tgc ccc ggt atg caa ctc gga ctc tac gcg cta gag acg 1453
Arg Arg Ser Cys Pro Gly Met Gln Leu Gly Leu Tyr Ala Leu Glu Thr
445 450 455 460

act gtg gct cac ctc ctt cac tgt ttc acg tgg gag ttg ccg gac ggg 1501
Thr Val Ala His Leu Leu His Cys Phe Thr Trp Glu Leu Pro Asp Gly
465 470 475

atg aaa ccg agt gaa ctc gag atg aat gat gtg ttt gga ctc acc gcg 1549
Met Lys Pro Ser Glu Leu Glu Met Asn Asp Val Phe Gly Leu Thr Ala
480 485 490

cca aga gcg att cga ctc acc gcc gtg ccg agt cca cgc ctt ctc tgt 1597
Pro Arg Ala Ile Arg Leu Thr Ala Val Pro Ser Pro Arg Leu Leu Cys
495 500 505

cct ctc tat tgatcgaatg attgggggag ctttgtggag gggcttttat 1646
Pro Leu Tyr
510

ggagactcta tatatagatg ggaagtgaaa caacgacagg tgaatgcttg gatttttggt 1706

atatattggg gagggagggg aaaaaaaaaa taatgaaagg aaagaaaaga gagaatttga 1766

atttctcttc ctctgtggat aaaagcctcg tttttaattg tttttatgtg gagatatttg 1826

tgtttgttta tttttatctc tttttttgca ataacactca aaaataaaaa aaaaaaa 1883

<210> 4
<211> 511
<212> PRT
<213> Liquidambar styraciflua

<400> 4
Met Asp Ser Ser Leu His Glu Ala Leu Gln Pro Leu Pro Met Thr Leu
1 5 10 15

Phe Phe Ile Ile Pro Leu Leu Leu Leu Leu Gly Leu Val Ser Arg Leu
20 25 30

Arg Gln Arg Leu Pro Tyr Pro Pro Gly Pro Lys Gly Leu Pro Val Ile
35 40 45

Gly Asn Met Leu Met Met Asp Gln Leu Thr His Arg Gly Leu Ala Lys
50 55 60

Leu Ala Lys Gln Tyr Gly Gly Leu Phe His Leu Lys Met Gly Phe Leu
65 70 75 80

His Met Val Ala Val Ser Thr Pro Asp Met Ala Arg Gln Val Leu Gln
85 90 95

Val Gln Asp Asn Ile Phe Ser Asn Arg Pro Ala Thr Ile Ala Ile Ser
100 105 110

Tyr Leu Thr Tyr Asp Arg Ala Asp Met Ala Phe Ala His Tyr Gly Pro
115 120 125

Phe Trp Arg Gln Met Arg Lys Leu Cys Val Met Lys Leu Phe Ser Arg
130 135 140

Lys Arg Ala Glu Ser Trp Glu Ser Val Arg Asp Glu Val Asp Ser Ala
145 150 155 160

Val Arg Val Val Ala Ser Asn Ile Gly Ser Thr Val Asn Ile Gly Glu
165 170 175

Leu Val Phe Ala Leu Thr Lys Asn Ile Thr Tyr Arg Ala Ala Phe Gly
180 185 190

Thr Ile Ser His Glu Asp Gln Asp Glu Phe Val Ala Ile Leu Gln Glu
195 200 205

Phe Ser Gln Leu Phe Gly Ala Phe Asn Ile Ala Asp Phe Ile Pro Trp
210 215 220

Leu Lys Trp Val Pro Gln Gly Ile Asn Val Arg Leu Asn Lys Ala Arg
225 230 235 240

Gly Ala Leu Asp Gly Phe Ile Asp Lys Ile Ile Asp Asp His Ile Gln
245 250 255

Lys Gly Ser Lys Asn Ser Glu Glu Val Asp Thr Asp Met Val Asp Asp
260 265 270

Leu Leu Ala Phe Tyr Gly Glu Glu Ala Lys Val Ser Glu Ser Asp Asp
275 280 285

Leu Gln Asn Ser Ile Lys Leu Thr Lys Asp Asn Ile Lys Ala Ile Met
290 295 300

Asp Val Met Phe Gly Gly Thr Glu Thr Val Ala Ser Ala Ile Glu Trp
305 310 315 320

Ala Met Thr Glu Leu Met Lys Ser Pro Glu Asp Leu Lys Lys Val Gln
325 330 335

Gln Glu Leu Ala Val Val Val Gly Leu Asp Arg Arg Val Glu Glu Lys
340 345 350

Asp Phe Glu Lys Leu Thr Tyr Leu Lys Cys Val Leu Lys Glu Val Leu
355 360 365

Arg Leu His Pro Pro Ile Pro Leu Leu Leu His Glu Thr Ala Glu Asp
370 375 380

Ala Glu Val Gly Gly Tyr Tyr Ile Pro Ala Lys Ser Arg Val Met Ile
385 390 395 400

Asn Ala Cys Ala Ile Gly Arg Asp Lys Asn Ser Trp Ala Asp Pro Asp
405 410 415

Thr Phe Arg Pro Ser Arg Phe Leu Lys Asp Gly Val Pro Asp Phe Lys
420 425 430

Gly Asn Asn Phe Glu Phe Ile Pro Phe Gly Ser Gly Arg Arg Ser Cys
435 440 445

Pro Gly Met Gln Leu Gly Leu Tyr Ala Leu Glu Thr Thr Val Ala His
450 455 460

Leu Leu His Cys Phe Thr Trp Glu Leu Pro Asp Gly Met Lys Pro Ser
465 470 475 480

Glu Leu Glu Met Asn Asp Val Phe Gly Leu Thr Ala Pro Arg Ala Ile
485 490 495

Arg Leu Thr Ala Val Pro Ser Pro Arg Leu Leu Cys Pro Leu Tyr
500 505 510

<210> 5
<211> 1380

<212> DNA
<213> Liquidambar styraciflua

<220>
<221> CDS
<222> (67)..(1170)

<400> 5
cggcacgagc cctacctcct ttcttggaaa aatttcccca ttcgatcaca atccgggcct 60

caaaaa atg gga tca aca agc gaa acg aag atg agc ccg agt gaa gca 108
Met Gly Ser Thr Ser Glu Thr Lys Met Ser Pro Ser Glu Ala
1 5 10

gca gca gca gaa gaa gaa gca ttc gta ttc gct atg caa tta acc agt 156
Ala Ala Ala Glu Glu Glu Ala Phe Val Phe Ala Met Gln Leu Thr Ser
15 20 25 30

gct tca gtt ctt ccc atg gtc cta aaa tca gcc ata gag ctc gac gtc 204
Ala Ser Val Leu Pro Met Val Leu Lys Ser Ala Ile Glu Leu Asp Val
35 40 45

tta gaa atc atg gct aaa gct ggt cca ggt gcg cac ata tcc aca tct 252
Leu Glu Ile Met Ala Lys Ala Gly Pro Gly Ala His Ile Ser Thr Ser
50 55 60

gac ata gcc tct aag ctg ccc aca aag aat cca gat gca gcc gtc atg 300
Asp Ile Ala Ser Lys Leu Pro Thr Lys Asn Pro Asp Ala Ala Val Met
65 70 75

ctt gac cgt atg ctc cgc ctc ttg gct agc tac tct gtt cta acg tgc 348
Leu Asp Arg Met Leu Arg Leu Leu Ala Ser Tyr Ser Val Leu Thr Cys
80 85 90

tct ctc cgc acc ctc cct gac ggc aag atc gag agg ctt tac ggc ctt 396
Ser Leu Arg Thr Leu Pro Asp Gly Lys Ile Glu Arg Leu Tyr Gly Leu
95 100 105 110

gca ccc gtt tgt aaa ttc ttg acc aga aac gat gat gga gtc tcc ata 444
Ala Pro Val Cys Lys Phe Leu Thr Arg Asn Asp Asp Gly Val Ser Ile
115 120 125

gcc gct ctg tct ctc atg aat caa gac aag gtc ctc atg gag agc tgg 492
Ala Ala Leu Ser Leu Met Asn Gln Asp Lys Val Leu Met Glu Ser Trp
130 135 140

tac cac ttg acc gag gca gtt ctt gaa ggt gga att cca ttt aac aag 540
Tyr His Leu Thr Glu Ala Val Leu Glu Gly Gly Ile Pro Phe Asn Lys

145 150 155

gcc tat gga atg aca gca ttt gag tac cat ggc acc gat ccc aga ttc 588
Ala Tyr Gly Met Thr Ala Phe Glu Tyr His Gly Thr Asp Pro Arg Phe
160 165 170

aac aca gtt ttc aac aat gga atg tcc aat cat tcg acc att acc atg 636
Asn Thr Val Phe Asn Asn Gly Met Ser Asn His Ser Thr Ile Thr Met
175 180 185 190

aag aaa atc ctt gag act tac aaa ggg ttc gag gga ctt gga tct gtg 684
Lys Lys Ile Leu Glu Thr Tyr Lys Gly Phe Glu Gly Leu Gly Ser Val
195 200 205

gtt gat gtt ggt ggt ggc act ggt gcc cac ctt aac atg att atc gct 732
Val Asp Val Gly Gly Gly Thr Gly Ala His Leu Asn Met Ile Ile Ala
210 215 220

aaa tac ccc atg atc aag ggc att aac ttc gac ttg cct cat gtt att 780
Lys Tyr Pro Met Ile Lys Gly Ile Asn Phe Asp Leu Pro His Val Ile
225 230 235

gag gag gct ccc tcc tat cct ggt gtg gag cat gtt ggt gga gat atg 828
Glu Glu Ala Pro Ser Tyr Pro Gly Val Glu His Val Gly Gly Asp Met
240 245 250

ttt gtt agt gtt cca aaa gga gat gcc att ttc atg aag tgg ata tgt 876
Phe Val Ser Val Pro Lys Gly Asp Ala Ile Phe Met Lys Trp Ile Cys
255 260 265 270

cat gat tgg agc gat gaa cac tgc ttg aag ttt ttg aag aaa tgt tat 924
His Asp Trp Ser Asp Glu His Cys Leu Lys Phe Leu Lys Lys Cys Tyr
275 280 285

gaa gca ctt cca acc aat ggg aag gtg atc ctt gct gaa tgc atc ctc 972
Glu Ala Leu Pro Thr Asn Gly Lys Val Ile Leu Ala Glu Cys Ile Leu
290 295 300

ccc gtg gcg cca gac gca agc ctc ccc act aag gca gtg gtc cat att 1020
Pro Val Ala Pro Asp Ala Ser Leu Pro Thr Lys Ala Val Val His Ile
305 310 315

gat gtc atc atg ttg gct cat aac cca ggt ggg aaa gag aga act gag 1068
Asp Val Ile Met Leu Ala His Asn Pro Gly Gly Lys Glu Arg Thr Glu
320 325 330

aag gag ttt gag gcc ttg gcc aag ggg gct gga ttt gaa ggt ttc cga 1116
Lys Glu Phe Glu Ala Leu Ala Lys Gly Ala Gly Phe Glu Gly Phe Arg

335 340 345 350

gta gta gcc tcg tgc gct tac aat aca tgg atc atc gaa ttt ttg aag 1164
Val Val Ala Ser Cys Ala Tyr Asn Thr Trp Ile Ile Glu Phe Leu Lys
355 360 365

aag att tgagtcctta ctcggctttg agtacataat accaactcct tttggttttc 1220
Lys Ile

gagattgtga ttgtgattgt gattgtctct ctttcgcagt tggccttatg atataatgta 1280

tcgttaactc gatcacagaa gtgcaaaaga cagtgaatgt acactgcttt ataaaataaa 1340

aattttaaga ttttgattca tgtaaaaaa aaaaaaaaaa 1380

<210> 6
<211> 368
<212> PRT
<213> Liquidambar styraciflua

<400> 6
Met Gly Ser Thr Ser Glu Thr Lys Met Ser Pro Ser Glu Ala Ala Ala
1 5 10 15

Ala Glu Glu Glu Ala Phe Val Phe Ala Met Gln Leu Thr Ser Ala Ser
20 25 30

Val Leu Pro Met Val Leu Lys Ser Ala Ile Glu Leu Asp Val Leu Glu
35 40 45

Ile Met Ala Lys Ala Gly Pro Gly Ala His Ile Ser Thr Ser Asp Ile
50 55 60

Ala Ser Lys Leu Pro Thr Lys Asn Pro Asp Ala Ala Val Met Leu Asp
65 70 75 80

Arg Met Leu Arg Leu Leu Ala Ser Tyr Ser Val Leu Thr Cys Ser Leu
85 90 95

Arg Thr Leu Pro Asp Gly Lys Ile Glu Arg Leu Tyr Gly Leu Ala Pro
100 105 110

Val Cys Lys Phe Leu Thr Arg Asn Asp Asp Gly Val Ser Ile Ala Ala
115 120 125

Leu Ser Leu Met Asn Gln Asp Lys Val Leu Met Glu Ser Trp Tyr His
130 135 140

Leu Thr Glu Ala Val Leu Glu Gly Gly Ile Pro Phe Asn Lys Ala Tyr
145 150 155 160

Gly Met Thr Ala Phe Glu Tyr His Gly Thr Asp Pro Arg Phe Asn Thr
165 170 175

Val Phe Asn Asn Gly Met Ser Asn His Ser Thr Ile Thr Met Lys Lys
180 185 190

Ile Leu Glu Thr Tyr Lys Gly Phe Glu Gly Leu Gly Ser Val Val Asp
195 200 205

Val Gly Gly Gly Thr Gly Ala His Leu Asn Met Ile Ile Ala Lys Tyr
210 215 220

Pro Met Ile Lys Gly Ile Asn Phe Asp Leu Pro His Val Ile Glu Glu
225 230 235 240

Ala Pro Ser Tyr Pro Gly Val Glu His Val Gly Gly Asp Met Phe Val
245 250 255

Ser Val Pro Lys Gly Asp Ala Ile Phe Met Lys Trp Ile Cys His Asp
260 265 270

Trp Ser Asp Glu His Cys Leu Lys Phe Leu Lys Lys Cys Tyr Glu Ala
275 280 285

Leu Pro Thr Asn Gly Lys Val Ile Leu Ala Glu Cys Ile Leu Pro Val
290 295 300

Ala Pro Asp Ala Ser Leu Pro Thr Lys Ala Val Val His Ile Asp Val
305 310 315 320

Ile Met Leu Ala His Asn Pro Gly Gly Lys Glu Arg Thr Glu Lys Glu
325 330 335

Phe Glu Ala Leu Ala Lys Gly Ala Gly Phe Glu Gly Phe Arg Val Val
340 345 350

Ala Ser Cys Ala Tyr Asn Thr Trp Ile Ile Glu Phe Leu Lys Lys Ile
355 360 365

<210> 7
<211> 2025
<212> DNA
<213> Liquidambar styraciflua

<220>
<221> CDS
<222> (60)..(1679)

<400> 7
cggcacgagc tcattttcca cttctggttt gatctctgca attcttccat cagtcccta 59

atg gag acc caa aca aaa caa gaa gaa atc ata tat cgg tcg aaa ctc 107
Met Glu Thr Gln Thr Lys Gln Glu Glu Ile Ile Tyr Arg Ser Lys Leu
1 5 10 15

ccc gat atc tac atc ccc aaa cac ctc cct tta cat tcg tat tgt ttc 155
Pro Asp Ile Tyr Ile Pro Lys His Leu Pro Leu His Ser Tyr Cys Phe
20 25 30

gag aac atc tca cag ttc ggc tcc cgc ccc tgt ctg atc aat ggc gca 203
Glu Asn Ile Ser Gln Phe Gly Ser Arg Pro Cys Leu Ile Asn Gly Ala
35 40 45

acg ggc aag tat tac aca tat gct gag gtt gag ctc att gcg cgc aag 251
Thr Gly Lys Tyr Tyr Thr Tyr Ala Glu Val Glu Leu Ile Ala Arg Lys
50 55 60

gtc gca tcc ggc ctc aac aaa ctc ggc gtt cga caa ggt gac atc atc 299
Val Ala Ser Gly Leu Asn Lys Leu Gly Val Arg Gln Gly Asp Ile Ile
65 70 75 80

atg ctt ttg cta ccc aac tcg ccg gag ttc gtg ttt tca att ctc ggc 347
Met Leu Leu Leu Pro Asn Ser Pro Glu Phe Val Phe Ser Ile Leu Gly
85 90 95

gca tcc tac cgc ggg gct gcc gcc acc gcc gca aac ccg ttt tat acc 395
Ala Ser Tyr Arg Gly Ala Ala Ala Thr Ala Ala Asn Pro Phe Tyr Thr
100 105 110

cct gcc gag atc agg aag caa gcc aaa acc tcc aac gcc agg ctt att 443
Pro Ala Glu Ile Arg Lys Gln Ala Lys Thr Ser Asn Ala Arg Leu Ile
115 120 125

atc aca cat gcc tgt tac tat gag aaa gtg aag gac ttg gtg gaa gag 491
Ile Thr His Ala Cys Tyr Tyr Glu Lys Val Lys Asp Leu Val Glu Glu
130 135 140

aac gtt gcc aag atc ata tgt ata gac tca ccc ccg gac ggt tgt ttg 539
Asn Val Ala Lys Ile Ile Cys Ile Asp Ser Pro Pro Asp Gly Cys Leu
145 150 155 160

```
cac ttc tcg gag ctg agt gag gcg gac gag aac gac atg ccc aat gta     587
His Phe Ser Glu Leu Ser Glu Ala Asp Glu Asn Asp Met Pro Asn Val
                165                 170                 175

gag att gac ccc gat gat gtg gtg gcg ctg ccg tac tcg tca ggg acg     635
Glu Ile Asp Pro Asp Asp Val Val Ala Leu Pro Tyr Ser Ser Gly Thr
            180                 185                 190

acg ggt tta cca aag ggg gtg atg cta aca cac aag gga caa gtg acg     683
Thr Gly Leu Pro Lys Gly Val Met Leu Thr His Lys Gly Gln Val Thr
        195                 200                 205

agt gtg gcg caa cag gtg gac gga gag aat ccg aac ctg tat ata cat     731
Ser Val Ala Gln Gln Val Asp Gly Glu Asn Pro Asn Leu Tyr Ile His
    210                 215                 220

agc gag gac gtg gtt ctg tgc gtg ttg cct ctg ttt cac atc tac tcg     779
Ser Glu Asp Val Val Leu Cys Val Leu Pro Leu Phe His Ile Tyr Ser
225                 230                 235                 240

atg aac gtc atg ttt tgc ggg tta cga gtt ggt gcg gcg att ctg att     827
Met Asn Val Met Phe Cys Gly Leu Arg Val Gly Ala Ala Ile Leu Ile
                245                 250                 255

atg cag aaa ttt gaa ata tat ggg ttg tta gag ctg gtc aga agt aca     875
Met Gln Lys Phe Glu Ile Tyr Gly Leu Leu Glu Leu Val Arg Ser Thr
            260                 265                 270

ggt gac cat cat gcc tat cgt aca ccc atc gta ttg gca atc tcc aag     923
Gly Asp His His Ala Tyr Arg Thr Pro Ile Val Leu Ala Ile Ser Lys
        275                 280                 285

act ccg gat ctt cac aac tat gat gtg tcc tcc att cgg act gtc atg     971
Thr Pro Asp Leu His Asn Tyr Asp Val Ser Ser Ile Arg Thr Val Met
    290                 295                 300

tca ggt gcg gct cct ctg ggc aag gaa ctt gaa gat tct gtc aga gct     1019
Ser Gly Ala Ala Pro Leu Gly Lys Glu Leu Glu Asp Ser Val Arg Ala
305                 310                 315                 320

aag ttt ccc acc gcc aaa ctt ggt cag gga tat gga atg acg gag gca     1067
Lys Phe Pro Thr Ala Lys Leu Gly Gln Gly Tyr Gly Met Thr Glu Ala
                325                 330                 335

ggg ccc gtg cta gcg atg tgt ttg gca ttt gcc aag gaa ggg ttt gaa     1115
Gly Pro Val Leu Ala Met Cys Leu Ala Phe Ala Lys Glu Gly Phe Glu
            340                 345                 350
```

ata aaa tcg ggg gca tct gga act gtt tta agg aac gca cag atg aag 1163
Ile Lys Ser Gly Ala Ser Gly Thr Val Leu Arg Asn Ala Gln Met Lys
355 360 365

att gtg gac cct gaa acc ggt gtc act ctc cct cga aac caa ccc gga 1211
Ile Val Asp Pro Glu Thr Gly Val Thr Leu Pro Arg Asn Gln Pro Gly
370 375 380

gag att tgc att aga gga gac caa atc atg aaa ggt tat ctt aat gat 1259
Glu Ile Cys Ile Arg Gly Asp Gln Ile Met Lys Gly Tyr Leu Asn Asp
385 390 395 400

cct gag gcg acg gag aga acc ata gac aag gaa ggt tgg tta cac aca 1307
Pro Glu Ala Thr Glu Arg Thr Ile Asp Lys Glu Gly Trp Leu His Thr
405 410 415

ggt gat gtg ggc tac atc gac gat gac act gag ctc ttc att gtt gat 1355
Gly Asp Val Gly Tyr Ile Asp Asp Asp Thr Glu Leu Phe Ile Val Asp
420 425 430

cgg ttg aag gaa ctg atc aaa tac aaa ggg ttt cag gtg gca ccc gct 1403
Arg Leu Lys Glu Leu Ile Lys Tyr Lys Gly Phe Gln Val Ala Pro Ala
435 440 445

gag ctt gag gcc atg ctc ctc aac cat ccc aac atc tct gat gct gcc 1451
Glu Leu Glu Ala Met Leu Leu Asn His Pro Asn Ile Ser Asp Ala Ala
450 455 460

gtc gtc cca atg aaa gac gat gaa gct gga gag ctc cct gtg gcg ttt 1499
Val Val Pro Met Lys Asp Asp Glu Ala Gly Glu Leu Pro Val Ala Phe
465 470 475 480

gtt gta aga tca gat ggt tct cag ata tcc gag gct gaa atc agg caa 1547
Val Val Arg Ser Asp Gly Ser Gln Ile Ser Glu Ala Glu Ile Arg Gln
485 490 495

tac atc gca aaa cag gtg gtt ttt tat aaa aga ata cat cgc gta ttt 1595
Tyr Ile Ala Lys Gln Val Val Phe Tyr Lys Arg Ile His Arg Val Phe
500 505 510

ttc gtc gaa gcc att cct aaa gcg ccc tct ggc aaa atc ttg cgg aag 1643
Phe Val Glu Ala Ile Pro Lys Ala Pro Ser Gly Lys Ile Leu Arg Lys
515 520 525

gac ctg aga gcc aaa ttg gcg tct ggt ctt ccc aat taattctcat 1689
Asp Leu Arg Ala Lys Leu Ala Ser Gly Leu Pro Asn
530 535 540

tcgctaccct cctttctctt atcatacgcc aacacgaacg aagaggctca attaaacgct 1749

gctcattcga agcggctcaa ttaaagctgc tcattcatgt ccaccgagtg ggcagcctgt 1809

cttgttggga tgttctttca tttgattcag ctgtgagaag ccagaccctc attatttatt 1869

gtgaaattca caagaatgtc tgtaaatcga tgttgtgagt gatgggtttc aaaacacttt 1929

tgacattgtt tacgttgtat ttcctgctgt tgaaaataac tactttgtat gacttttatt 1989

tgggaagata acctttcaaa aaaaaaaaaa aaaaaa 2025

<210> 8
<211> 540
<212> PRT
<213> Liquidambar styraciflua

<400> 8
Met Glu Thr Gln Thr Lys Gln Glu Glu Ile Ile Tyr Arg Ser Lys Leu
1 5 10 15

Pro Asp Ile Tyr Ile Pro Lys His Leu Pro Leu His Ser Tyr Cys Phe
20 25 30

Glu Asn Ile Ser Gln Phe Gly Ser Arg Pro Cys Leu Ile Asn Gly Ala
35 40 45

Thr Gly Lys Tyr Tyr Thr Tyr Ala Glu Val Glu Leu Ile Ala Arg Lys
50 55 60

Val Ala Ser Gly Leu Asn Lys Leu Gly Val Arg Gln Gly Asp Ile Ile
65 70 75 80

Met Leu Leu Leu Pro Asn Ser Pro Glu Phe Val Phe Ser Ile Leu Gly
85 90 95

Ala Ser Tyr Arg Gly Ala Ala Ala Thr Ala Ala Asn Pro Phe Tyr Thr
100 105 110

Pro Ala Glu Ile Arg Lys Gln Ala Lys Thr Ser Asn Ala Arg Leu Ile
115 120 125

Ile Thr His Ala Cys Tyr Tyr Glu Lys Val Lys Asp Leu Val Glu Glu
130 135 140

Asn Val Ala Lys Ile Ile Cys Ile Asp Ser Pro Pro Asp Gly Cys Leu
145 150 155 160

His Phe Ser Glu Leu Ser Glu Ala Asp Glu Asn Asp Met Pro Asn Val
165 170 175

Glu Ile Asp Pro Asp Asp Val Val Ala Leu Pro Tyr Ser Ser Gly Thr
180 185 190

Thr Gly Leu Pro Lys Gly Val Met Leu Thr His Lys Gly Gln Val Thr
195 200 205

Ser Val Ala Gln Gln Val Asp Gly Glu Asn Pro Asn Leu Tyr Ile His
210 215 220

Ser Glu Asp Val Val Leu Cys Val Leu Pro Leu Phe His Ile Tyr Ser
225 230 235 240

Met Asn Val Met Phe Cys Gly Leu Arg Val Gly Ala Ala Ile Leu Ile
245 250 255

Met Gln Lys Phe Glu Ile Tyr Gly Leu Leu Glu Leu Val Arg Ser Thr
260 265 270

Gly Asp His His Ala Tyr Arg Thr Pro Ile Val Leu Ala Ile Ser Lys
275 280 285

Thr Pro Asp Leu His Asn Tyr Asp Val Ser Ser Ile Arg Thr Val Met
290 295 300

Ser Gly Ala Ala Pro Leu Gly Lys Glu Leu Glu Asp Ser Val Arg Ala
305 310 315 320

Lys Phe Pro Thr Ala Lys Leu Gly Gln Gly Tyr Gly Met Thr Glu Ala
325 330 335

Gly Pro Val Leu Ala Met Cys Leu Ala Phe Ala Lys Glu Gly Phe Glu
340 345 350

Ile Lys Ser Gly Ala Ser Gly Thr Val Leu Arg Asn Ala Gln Met Lys
355 360 365

Ile Val Asp Pro Glu Thr Gly Val Thr Leu Pro Arg Asn Gln Pro Gly
370 375 380

Glu Ile Cys Ile Arg Gly Asp Gln Ile Met Lys Gly Tyr Leu Asn Asp
385 390 395 400

Pro Glu Ala Thr Glu Arg Thr Ile Asp Lys Glu Gly Trp Leu His Thr
405 410 415

Gly Asp Val Gly Tyr Ile Asp Asp Asp Thr Glu Leu Phe Ile Val Asp
420 425 430

Arg Leu Lys Glu Leu Ile Lys Tyr Lys Gly Phe Gln Val Ala Pro Ala
435 440 445

Glu Leu Glu Ala Met Leu Leu Asn His Pro Asn Ile Ser Asp Ala Ala
450 455 460

Val Val Pro Met Lys Asp Asp Glu Ala Gly Glu Leu Pro Val Ala Phe
465 470 475 480

Val Val Arg Ser Asp Gly Ser Gln Ile Ser Glu Ala Glu Ile Arg Gln
485 490 495

Tyr Ile Ala Lys Gln Val Val Phe Tyr Lys Arg Ile His Arg Val Phe
500 505 510

Phe Val Glu Ala Ile Pro Lys Ala Pro Ser Gly Lys Ile Leu Arg Lys
515 520 525

Asp Leu Arg Ala Lys Leu Ala Ser Gly Leu Pro Asn
530 535 540

<210> 9
<211> 1544
<212> DNA
<213> Pinus taeda

<400> 9
aaagataata tatgtgtatg cctactacta cacattgttt tgaagtgtgt aaacatagtg 60

caacactagg aggactcaca atgagcactt gttgacatga aactagctaa atgcccaaca 120

atattagtga aagctagtta aactaacccc tttgactttc aagatgatat atttatatcc 180

ctactacgtc ttcctctttt tgtctttctc ttgtgattaa accttccttg aaacaattct 240

caaatgtaaa attaaacctt gaaacttgta gagaccaaac ttccctagga gaaaccacat 300

ttatgacaac atatatacac caacccattg catactataa tattggaatt acctgcagcg 360

aacgaaagaa acgctgtctc accaactcgt gcactacatc ccgaaactta accttcccct 420

gatacagatt gaagagccga aaaaagcgtg catccaaatt tctggtatgg tgaggagccg 480

aaaaacgcgt gcgcctaatt tttttgagat gggccggaaa ataatgcgtg catctaaatt 540

ttcacgtgtc gcgtattggc gaggttgcgc tgaatgtgat cctgtgcgtg agccacattc 600

attccattgg ttgacccgcc ggtaccgcga ggaccgtggg gtctcacaga tacgcggatg 660

gtggatcagc actgagaaga ttagatgatg accaggcggg catttgaagt aaaaacttgg 720

gggtggttgg caagtacgcg acaaagaggg gtagtgcgca aggaagcgag ttggatgcaa 780

ataatattac aaagtgggtt ggtgggcatg agcatcaacc agaatgatgt tgttgctggt 840

tccgtgcaaa ttctgaccag tagtttgaac aatactaccc aacttgtttt tggtaaaaca 900

tgaagtgggt aaggagaatt gaacttacgt ctcatggtaa agggcaaggg caaatgactt 960

aacacatacc tttaactaat aaaaataccc ctaacaaata cgaaaacgaa tgagttatca 1020

cagaccttca actaataaga tagccatcag acccacatct cctgactgac caaaaacaaa 1080

tgacttcaac caactaagat acccatcaaa gctaacccac aacccaattc ctcacttccc 1140

cttaccagac caaccaagca gacctacgcc attaactact ttaggacgtg ggaattgggg 1200

gtgccaccgt tgaagaatgg cactcagggt tggtaatccc tccacgtgta tgtagcagtc 1260

gtttggtgga gacggcgtgt ttgaatgtcc accttccagt ttggagaaca aggaaattgg 1320

gcttatatta ggcctggatc tcttgtttca gagcaggagt agttcaggac aggaactagc 1380

attcaagaat tcaattgccc tgccctgctc tgctctgctt tgctcaactt attgatccct 1440

gctctggttt gttcaatttc ttgacccctg ctgggttctg ctctggtttg cacactttct 1500

cgattatata agtcattttg gatccttgca aggaagagaa tatg 1544

<210> 10
<211> 659
<212> DNA
<213> Pinus taeda

<400> 10
aaacaccaat ttaatgggat ttcagatttg tatcccatgc tattggctaa ggcatttttc 60

ttattgtaat ctaaccaatt ctaatttcca ccctggtgtg aactgactga caaatgcggt 120

ccgaaaacag cgaatgaaat gtctgggtga tcggtcaaac aagcggtggg cgagagagcg 180

cgggtgttgg cctagccggg atgggggtag gtagacggcg tattaccggc gagttgtccg 240

aatggagttt tcggggtagg tagtaacgta gacgtcaatg gaaaaagtca taatctccgt 300

caaaaatcca accgctcctt cacatcgcag agttggtggc cacgggaccc tccacccact 360

cactcaatcg atcgcctgcc gtggttgccc attattcaac catacgccac ttgactcttc 420

accaacaatt ccaggccggc tttctataca atgtactgca caggaaaatc caatataaaa 480

agccggcctc tgcttccttc tcagtagccc ccagctcatt caattcttcc cactgcaggc 540

tacatttgtc agacacgttt tccgccattt ttcgcctgtt tctgcggaga atttgatcag 600

gttcggattg ggattgaatc aattgaaagg tttttatttt cagtatttcg atcgccatg 659

<210> 11
<211> 2251
<212> DNA
<213> Pinus taeda

<400> 11
ggccgggtgg tgacatttat tcataaattc atctcaaaac aagaaggatt tacaaaaata 60

aaagaaaaca aaattttcat ctttaacata attataattg tgttcacaaa attcaaactt 120

aaacccttaa tataaagaat ttctttcaac aatacacttt aatcacaact tcttcaatca 180

caacctcctc caacaaaatt aaaatagatt aataaataaa taaacttaac tatttaaaaa 240

aaaatattat acaaaattta ttaaaacttc aaaataaaca aactttttat acaaaattca 300

tcaaaacttt aaaataaagc taaacactga aaatgtgagt acatttaaaa ggacgctgat 360

cacaaaaatt ttgaaaacat aaacaaactt gaaactctac cttttaagaa tgagtttgtc 420

gtctcattaa ctcattagtt ttatagttcg aatccaatta acgtatcttt tattttatgg 480

aataagggtg ttttaataag tgattttggg attttttag taatttattt gtgatatgtt 540

atggagtttt taaaaatata tatatatata tatatttttg ggttgagttt acttaaaatt 600

tggaaaaggt tggtaagaac tataaattga gttgtgaatg agtgttttat ggattttta 660

agatgttaaa tttatatatg taattaaaat tttattttga ataacaaaaa ttataattgg 720

ataaaaaatt gttttgttaa atttagagta aaaatttcaa aatctaaaat aattaaacac 780

tattattttt aaaaaatttg ttggtaaatt ttatcttata tttaagttaa aatttagaaa 840

aaattaattt taaattaata aacttttgaa gtcaaatatt ccaaatattt tccaaaatat 900

taaatctatt ttgcattcaa aatacaattt aaataataaa acttcatgga atagattaac 960

caatttgtat aaaaaccaaa aatctcaaat aaaatttaaa ttacaaaaca ttatcaacat 1020

tatgatttca agaaagacaa taaccagttt ccaataaaat aaaaaacctc atggcccgta 1080

attaagatct cattaattaa ttcttatttt ttaatttttt tacatagaaa atatctttat 1140

attgtatcca agaaatatag aatgttctcg tccagggact attaatctcc aaacaagttt 1200

caaaatcatt acattaaagc tcatcatgtc atttgtggat tggaaattat attgtataag 1260

agaaatatag aatgttctcg tctagggact attaatttcc aaacaaattt caaaatcatt 1320

acattaaagc tcatcatgtc atttgtggat tggaaattag acaaaaaaaa tcccaaatat 1380

ttctctcaat ctcccaaaat atagttcgaa ctccatattt ttggaaattg agaatttttt 1440

tacccaataa tatatttttt tatacatttt agagattttc cagacatatt tgctctggga 1500

tttattggaa tgaaggttga gttataaact ttcagtaatc caagtatctt cggtttttga 1560

agatactaaa tccattatat aataaaaaca cattttaaac accaatttaa tgggatttca 1620

gatttgtatc ccatgctatt ggctaaggca tttttcttat tgtaatctaa ccaattctaa 1680

tttccaccct ggtgtgaact gactgacaaa tgcggtccga aaacagcgaa tgaaatgtct 1740

gggtgatcgg tcaaacaagc ggtgggcgag agagcgcggg tgttggccta gccgggatgg 1800

gggtaggtag acggcgtatt accggcgagt tgtccgaatg gagttttcgg ggtaggtagt 1860

aacgtagacg tcaatggaaa aagtcataat ctccgtcaaa aatccaaccg ctccttcaca 1920

tcgcagagtt ggtggccacg ggaccctcca cccactcact cgatcgcctg ccgtggttgc 1980

ccattattca accatacgcc acttgactct tcaccaacaa ttccaggccg gctttctata 2040

caatgtactg cacaggaaaa tccaatataa aaagccggcc tctgcttcct tctcagtagc 2100

ccccagctca ttcaattctt cccactgcag gctacatttg tcagacacgt tttccgccat 2160

ttttcgcctg tttctgcgga gaatttgatc aggttcggat tgggattgaa tcaattgaaa 2220

ggtttttatt ttcagtattt cgatcgccat g 2251

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/26784

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :C12N 15/29, 5/04, 15/82; A01H 4/00, 5/00
US CL :536/23.6; 435/69.1, 411, 419; 800/278, 295, 284, 319
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 536/23.6; 435/69.1, 411, 419; 800/278, 295, 284, 319

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

AGRICOLA, MEDLINE, CAPLUS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X -- Y	DWIVEDI et al. Modification of Lignin Biosynthesis in Transgenic Nicotiana Through Expression of an Antisense O-Methyltransferase Gene from Populus. Plant Molecular Biology. October 1994, Vol. 26, No. 1, pages 61-71, see the entire document.	1 --------------- 1-15, 17-21, 30-32, 36-37, 40, 42, 44
Y	STOMP et al. Transient Expression from Microprojectile-Mediated DNA Transfer in Pinus Taeda. Plant Cell Reports. 1991, Vol. 10, No. 4, pages 187-190, see the entire document.	1-15,17-21,30-32,36-37,40,42,44

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 MARCH 1999	15 APR 1999

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	D. Lawrence Jr. OUSAMA M-FAIZ ZAGHMOUT
Facsimile No. (703) 305-3230	Telephone No. (703) 308-0196

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/26784

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-15, 17-21, 30-32, 36-37, 40, 42, 44

Remark on Protest ☐ The additional search fees were accompanied by the applicant's protest.
☐ No protest accompanied the payment of additional search fees.